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ELEMENTS

OF

PHYSICS,

OR

NATURAL PHILOSOPHY,

GENERAL AND MEDICAL,

EXPLAINED INDEPENDENTLY OF

TECHNICAL MATHEMATICS.

By N. ARNOTT, M.D.,
OF THE ROYAL COLLEGE OF PHYSICIANS.

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ADVERTISEMENT.

THE Philosophy of *ponderable matter*, which forms the subject of this volume, under the heads of

Somatology,	*Hydraulics,*
Dynamics,	*Pneumatics,*
Mechanics,	and
Hydrostatics,	*Acoustics,*

is a complete subject in itself, and has often been published apart; but it was the author's intention originally to have included with it, in one thick volume, the Philosophy also of *imponderable matter*, under the heads of

Caloric,	*Electricity,*
Optics,	*Magnetism,*

and the elements of *Astronomy*. Of this second part, however, he now finds that it will be impossible for him to superintend the printing until the autumn. It consists of nearly three hundred pages, and may either remain as a separate volume, or be bound up with this first part.

The reader of this volume is requested to correct at once, the two following *errata*.

At page 487, in the last sentence of the paragraph, the words "as a measure" are wanting after the word "however;" and the whole sentence should stand after the second line of the page.

At page 512, the following, which is the third paragraph of the page, has been accidentally omitted.

"The truth explained above, that no kind of pump can lift fluid through pliant tubes, free to collapse, like the veins, renders it unnecessary to speak farther here of the pumping action of the heart, insisted on by Dr. Carson, or of that other action, mentioned in this work at p. 543, to which also he attributes great influence, *viz.* the tendency towards a vacuum external to the lungs and around the heart, produced by the disposition of the lungs to collapse. It may be remarked, however, that this last influence is more considerable, than the simple inspiratory action dwelt on by Dr. Barry, and operates during expiration nearly as much as during inspiration, varying in force with the degrees of expansion of the chest. It is weaker in the living than in the dead body, because the rigidity of the distended pulmonary arteries helps to support the weight of the lungs."

INTRODUCTION.

To appreciate the importance of PHYSICS, or NATURAL PHILOSOPHY, as an object of study to medical men, in common with all engaged in scientific pursuit, and indeed, in the present day, with all who pretend to a liberal education, we must take a rapid glance at the nature of human knowledge generally, and at its bearings on the existing condition of mankind. We shall therefore notice

The progressive condition of mankind,
Its dependence on increase of knowledge;
Mutual dependence of the branches of knowledge;
Natural order of study;
Importance of Physics.

While the inferior races of animals seem to have changed as little in any respect since the beginning of our records, as the trees and herbs of the thickets which give many of them shelter, the condition of man has fluctuated, and, on the whole, progressed in a very extraordinary manner. The inferior animals were formed by their Creator such, that within one life or generation, they should attain all the perfection of which their nature was susceptible. Their wants were either immediately provided for, as the clothing of feathers to the birds, and of furs to quadrupeds; or were so few and simple, that the supply was easy to very limited powers; and in a few cases, where considerable art was required, as by the bee in making its honey-cell, or by the bird in constructing its beautiful nest, a peculiar aptitude or instinct was bestowed. Thus a crocodile which issues from its egg in the warm sand, and never sees its parent, becomes as perfect and knowing as any crocodile that has lived before, or that will appear after it.—How different from all this is the story of man! He comes into the world the most helpless of living beings, and long continues so; and if deserted by parents at an early age, so that he can learn only what individual experience may teach him, as to a few has happened who have afterwards grown to maturity in woods and deserts, he grows up in some respects inferior to the nobler brutes. Now as regards many regions of the earth, history exhibits the early human inhabitants in states of ignorance and barbarism, which civilized men shudder to contemplate. But these countries, occupied formerly by straggling hordes of miserable savages, who could scarcely defend themselves against the wild beasts that shared the woods with them, and the inclemencies of the weather, and the consequences of want and fatigue, and who to each other were often more dangerous than any wild beasts, unceasingly warring among themselves, and destroying each other with every species of savage, and even cannibal cruelty—countries so occupied formerly, are now become the abodes of myriads of peaceful, civilized, and friendly men, and the desert and impenetrable forest, are changed into cultivated fields, rich gardens, and magnificent cities.

It is the strong intellect of man operating with the faculty of language as a means, which has gradually worked this wonderful change. By language fathers have communicated their gathered experience to their children, and these to succeeding children, with new accumulation; and when, after many generations, the precious store had grown until simple memory could retain no more, the arts of writing, and then of printing arose, making language visible and permanent, and enlarging illimitably the receptacles of knowledge. Language thus, at the present moment of the world's existence, may be said to bind the whole human race of uncounted millions into one gigantic rational being, whose memory reaches to the beginnings of written records, and retains imperishably the events that have occurred; whose judgment, analyzing the treasures of memory, has discovered many of the sublime and unchanging laws of nature, and has built on them all the arts of life, and through them piercing far into futurity, sees clearly events that are to come; and whose eyes and ears and observant mind are at this moment, in every corner of the earth, watching and recording new phenomena, for the purpose of still better comprehending the magnificence and beautiful order of creation, and of more worthily adoring its beneficent Author.

It might be very interesting to shew here, in detail, how the arts and civilization have progressed in accordance with the gradual increase of man's knowledge of the universe; but it would lead us too far from our main subject. We deem it right, however, to make evident to the student the arousing truths, that the progress is not yet at an end; that it has been vastly more rapid in recent times than ever; and that it seems still proceeding with increasing speed:—and we know not where the Creator has fixed the limit of the change! Although there are thousands of years in the records of the world, our BACON, who first taught the true way to investigate nature, lived but the other day. NEWTON followed him, and illustrated his precepts by the most sublime discoveries that one man has ever made. HARVEY detected the circulation of the blood only two hundred years ago. ADAM SMITH, Dr. BLACK, and JAMES WATT were friends; and the last, whose steam-engines are now changing the relations of empires, is scarcely cold in his grave. JOHN HUNTER died not long ago; and HERSCHELL's account of the newly-discovered planets and structure of the heavens, are in the late numbers of our scientific journals.—And these illustrious Britons have worthy successors treading in their steps. On the continent of Europe, during the same period, a corresponding constellation of genius has shone; and living LAPLACE is the bright star that connects the past with the future.

But there is a change taking place in the world, connected closely with the progress of science, yet distinct from it, and more important than half of the scientific discoveries;—it is the *diffusion of knowledge* among the mass of mankind. Formerly knowledge was shut up in convents and universities, and in books written in the dead languages; or, if in the living languages, they were so abstruse and artificial, that only a few persons had access to their meaning:—and thus, considering the human race as one great intellectual creature, a small fraction only of its intellect was allowed to come into contact with science, and therefore into activity; and that fraction was often rendered indolent, because left without sufficient motive to exertion. The progress of science in those times was correspondingly slow. Now, however, the strong barriers which confined the stores of wisdom have been thrown down, and a flood overspreads the earth; old establishments are beginning to adapt themselves to the spirit of the age; new establishments are arising; the inferior schools are introducing improved systems of instruction; and good books are rendering every man's fire-side a school. From all these causes there is growing up an enlightened public opinion, which quickens and directs the progress of every art and science, and which, through the medium of a free press, although overlooked by many, is now rapidly becoming the governing influence in the world with respect to all the great interests of humanity. In Great Britain the progress of enlightened public opinion has been more decided than in any other state. The early consequences were more free political institutions; and these have been followed by greater and greater improvements, until Britain is become truly the Queen of the Nations. A noble colony of her children, imbued with her spirit, now occupies a magnificent territory in the new world of Columbus; and although it has been independent as yet for only half a century, it has already more people than Spain, and promises soon to be second to no nation on earth. The example of the United English States has aided in rendering the American hemisphere the cradle of many other gigantic states, all free and following the same steps. In the still more recently discovered continent of Australasia, which is larger than Europe, and empty of men, colonization is spreading with a rapidity never before witnessed, and that beautiful and rich portion of the earth will also soon be covered with the descendants of free-born and enlightened Englishmen. From thence still onward, they or their institutions will naturally spread over the vast archipelago of the Pacific Ocean, a track studded with islands of paradise.—Such, then, is the extraordinary moment of revolution or transit, in which the world at present exists!—And where, we may ask again, has the Creator predestined that the progress shall cease?—Thus far, at least, we know, that he has made our hearts rejoice to see the world filling with happy human beings, and to observe that the increase of the sciences can make the same spot maintain thousands in comfort, where with ignorance even hundreds had found but a scanty supply.

The progress of knowledge which has thus led from former barbarism to present civilization, has gone on by steps, which it is easy to point out; and it is very useful to consider these, because we thereby discover the relations and importance of the different branches of knowledge; and we obtain great facilities for studying science, and for quickening its farther progress.

The human mind, when originally directed to the almost infinity of objects in the universe around it, must soon have discovered that there were resemblances among them; in other words, that the infinity was only a repetition of a certain number of kinds, and that by studying carefully an exemplar of each kind, the limited power of memory might acquire a tolerably-correct knowledge of the whole. Now as this knowledge enabled persons more easily to obtain what was useful to them, and to avoid what was prejudicial, the desire to possess it must have arisen with the first exercise of reason. The labour of ages has at last produced nearly a complete arrangement of all the constituent materials of the universe, under three great classes of MINERALS, VEGETABLES, and ANIMALS. These classes are commonly called the *three kingdoms of nature*, and the minute description of the individual objects constitutes NATURAL HISTORY.—A complete museum of natural history may contain a specimen of almost every object included in these classes, so that a student within the limits of a common garden may be able, as it were, to examine the whole of the material universe.

While man was examining the *forms* and other qualities of the bodies around him, he could not avoid noticing also the *motions* or changes going on among them; and here, too, he would soon make the grand discovery, that there were resemblances in the multitude. Self-interest, as in the case of the bodies themselves, would prompt to careful classification; and in the present day, as the result of countless observations and experiments made through the series of ages, we are enabled to say, that all the *motions*, or *changes*, or *phenomena* (words synonimous here) of the universe, are merely a repetition and mixture of a few simple manners or kinds of motion, which are as constant and regular in every case, as where they produce the unvarying returns of day and night, and of the seasons. All these phenomena are referrible to four distinct classes, which we call *Physical*, *Chemical*, *Vital*, and *Mental*. The simple expressions which describe them are denominated *The Laws of Nature*, and as a body of knowledge, they constitute what is called SCIENCE or PHILOSOPHY, in contra-distinction to NATURAL HISTORY, already described. *Natural History* and *Science* make up the whole sum of our knowledge of nature.

To exemplify the process by which man discovers a general law of nature, we shall speak of the physical law of *gravity* or *attraction*: 1st. It was observed that bodies raised from the earth, and left unsupported, fell down; 2d. That flame, smoke, clouds, or vapours, when left free, ascended away from the earth:—it was supposed, therefore, to be a very general law, that things had *weight*; but that there were exceptions in such matters as now mentioned, which were in their nature *light* or ascending. 3d. It was discovered that our globe of earth is surrounded by an ocean of air, of which a cubic foot taken near the surface of the earth, weighs about an ounce; and it was then perceived that flame, smoke, vapour, &c. rise in the air for the same reason that oil rises in water, *viz.* because lighter than the fluid by which they are surrounded; and therefore, that nothing was known on earth naturally *light*, in the ancient sense of the word. 4th. It was found that bodies floating in water near to each other, approached and feebly cohered; that any contiguous hanging bodies were drawn towards each other, so as not to hang quite perpendicularly; that a plummet suspended near a hill was drawn towards the hill, and with force just so much less than the whole weight of the plummet, as the hill was smaller than the earth. It was thus proved that weight itself is only an instance of a more general law of mutual *attraction*, operating between all the constituent elements of this globe: and which is the cause of the rotundity of the globe, all the parts being drawn towards a common centre, as also of the form of dew-drops, rain-drops, globules of mercury, shot-lead, and of many other things. 5th. But it was farther observed, that all the heavenly bodies are round, and must, therefore, consist of material obeying the same law. And lastly, that these bodies, however distant, attract each other; for that the tides of our ocean rise in obedience to the attraction of the moon, and become *high* or *spring-tides*, when the moon and sun operate in the same direction. Thus the sublime truth was at last made evident, and by the genius of the immortal Newton, that attraction is the power which connects together the bodies of our solar system, at least, and probably is limited only by the bounds of the universe.

Who can but admire that the human mind should have power to discover in such variety and apparent opposition of facts the operation of a single principle! The process of analysing facts, whether learned by mere observation, or by contrived experiment, so as to deduce from them the general circumstance in which they resemble, is called the method of philosophising by *induction;* and such circumstance is the truth or law under which the facts are to be classed. All the knowledge of the course of nature which the human mind acquires during the progress from infancy to the commencement of methodical study, is obtained by this process, and it is one therefore which the mind naturally adopts. But there was required the power of one of the strongest intellects which has graced the world, that of BACON, to prove that it is only the same process carried further, which can lead to the higher objects of philosophy. The error of another powerful intellect, that of ARISTOTLE, who preferred *supposing* what the laws of nature should be (that is to say, forming *hypotheses*), and would then see only such facts as squared with his *hypotheses*, had kept the mind of the human race in darkness and slavery for two thousand years.

Acquaintance with the laws of nature has been very slowly obtained, owing to that complicacy of ordinary phenomena, which is produced by several laws operating together, and under great variety of circumstance. With respect to many laws of Chemistry and Life, men seem to be yet little further advanced, than they were with respect to the physical law of *attraction*, when they knew only that heavy things fell to the earth. But we have learned enough to perceive that the great universe is as simple and harmonious, as it is immense; and that the Creator, instead of interposing separately, or miraculously, in the common sense of the word, to produce every distinct phenomenon, has willed that all should proceed according to a few general laws.—There is nothing in nature so truly miraculous and adorable, as that the endless and beneficent variety of results which we see should spring from such simple elements. In times of ignorance men naturally attributed every occurrence which they did not understand, that is to say, which they could not refer to a general law, to a direct interference of supreme power. And thus for many ages, and among some nations still, eclipses, and earthquakes, and many diseases, particularly those of the mind, and the winds and weather, were or are accounted miraculous. Hence arose among heathens the barbarous sacrifices for propitiating or appeasing their offended deities. They had not yet risen to the sublime conception of one God, who said, "Let there be light," and it was so; and who also gave to the whole of nature permanent laws, which he allows men to discover for the direction of their conduct in life,—laws so unchanging, that men can calculate eclipses backward or forward for thousands of years, without erring by one beat of a pendulum; and as their knowledge of nature advances, they can anticipate and explain other events with equal precision. Even the wind and the rain, which, in common speech, are the types of uncertainty and change, obey laws as fixed as those of the sun and moon; and already, as regards many parts of the earth, men can foretel these without fear of being belied. They plan their voyages to suit the coming monsoons, and they prepare against the floods of the rainy seasons.

He who understands the laws of nature, even in the degree in which men now know them, has such clear prescience of the future, and of the effects which will arise from certain causes, that, in many cases, he can interpose and control events to answer his private ends. To a certain extent he thus commands nature, and, as expressed in the language of Lord Bacon, "his knowledge is power." Again, as all single material objects and states of objects in the universe, are results of antecedent operation of the laws of change, a man who first studies the laws, knows before-hand in great part the objects which he will meet with in examining nature, and he thus most remarkably diminishes the labour of studying *natural history*. He seems to learn by intuition. A well-informed man of the present day, may be said to possess, within the boundaries of his mind, the universe in miniature, in which he may contemplate at leisure past events, and the present, and the future. But let him not be misled by the pride of reason, which naturally arises from such considerations. All his calculations are yet founded on an assumption, that the laws of nature, as understood by him, have not changed, and will not change. Now, although thousands of years give countenance to the assumption, these thousands are still less to a past and a coming eternity, than the mid-day hour, which is an animalcule's life, to rolling ages—an animalcule which cannot know the morning, nor the evening, nor spring, nor winter.—Man, it is true, can foretel the change of day, and of season, and the coming of remote eclipses: but the mountains of the earth are daily diminishing by the action of winds, and rains and other unremitting causes, and the depths of the ocean are thereby filling up; and stars which his forefathers beheld bright in the firmament, are now dim, or have disappeared;—awful changes, of which his knowledge, founded on comparatively short experience, can tell him neither the beginning nor the end!

The general laws of nature, as stated above, are divisible into those of, 1st. *Physics*, often called *Natural Philosophy;* 2d. of *Chemistry;* 3d. of *Life*, commonly called *Physiology;* and, 4th. of *Mind:* and the four classes may be said to form the pyramid of Science, with Physics for the base; and the others succeeding in the order now mentioned, and having certain mutual relations figured by the parts of a pyramid.

Physics.—The laws of *Physics* govern every phenomenon of nature in which there is any sensible change of place, and they are themselves the sole causes of the greater part of all the phenomena. They *regulate* also those which *originate* from chemical action, and from the action of life.—The great Physical truths are now reduced to four, and are referred to by the words *atom, attraction, repulsion,* and *inertia.* It gives an astonishing, but true idea of the nature and importance of methodical *Science,* to be told that a man, who understands these words, *viz.* how the *atoms* of matter *attract,* and cling together to form masses, which are solid, liquid, or aeriform, according to the quantity of *repelling* heat among them, and which, owing to their *inertia* or stubbornness, gain and lose motion, in exact proportion to the force of attraction or repulsion acting on them, understands the greater part of the phenomena of nature; but such is the fact! *Solid* bodies, existing in conformity with these truths, exhibit all the phenomena of *Mechanics; Liquids* exhibit those of *Hydrostatics* and *Hydraulics; Airs,* those of *Pneumatics;* and so forth, as seen in the table of heads below, page xix. And the whole of this volume is merely a list of the most interesting physical phenomena, arranged in classes under these heads.

Chemistry.—Had there been only one kind of substance or matter in the universe, the laws of Physics would have explained all the phenomena; but there are *iron,* and *sulphur,* and *charcoal,* and about fifty others, which to the present state of science, appear essentially distinct. Now these, taken singly, obey the laws of Physics; but, if iron and sulphur be brought together and heated, they disappear as individuals, and unite into a new mass, which in most of its properties is unlike to either. Under new circumstances, the two substances will again separate, and assume their original forms. Such changes are called chemical, but during them, the substances are not at all withdrawn from the influence of the physical laws:—their weight or inertia, for instance, is not altered. Many chemical changes are immediately followed by physical changes, as when the new chemical arrangement produced among the intimate atoms of gunpowder by heat, causes the physical motion of the sudden expansion or explosion. And all the manipulations of Chemistry, as the transferring of gases from vessel to vessel, the weighing of bodies, pounding, grinding, &c. are directed by Physics alone. Chemistry is truly, then, as figured above, a superstructure on Physics, and cannot be understood or practised by a person ignorant of Physics. The chief objects of study which depend on Chemical, in conjunction with Physical laws, are enumerated in the table below, under the head of CHEMISTRY.

Life.—The most complicated state in which matter exists, is where, under the influence of life, it forms bodies with a curious internal structure of tubes an cavities, in which fluids are moving and producing incessant internal change. These are called *Organised Bodies*, because of the various *organs* which they contain; and they form two remarkable classes, the individuals of one of which are fixed to the soil, and are called *Vegetables;* and of the other, are endowed with power of locomotion, and are called *Animals.* The phenomena of growth, decay, death, sensation, self-motion, and many others belong to life, but from occurring all in material structures which subsist in obedience to the laws of physics and chemistry, the life may be considered as a superstructure on the other two, and cannot be studied independently of them. The phenomena of life, from thus involving generally the agency of all the sets of laws, are by far the most complex of any; and the discovery or detection of the peculiar *laws of life*, although these are as fixed as the laws of physics or chemistry, has been very slow, and is as yet far from being completed. We cannot as yet explain why the individuals of animal and vegetable classes live only for a limited time; why offspring inherit peculiarities of health or disease from the parents; why the various species continue distinct, &c. &c. But many powerful minds at the present day, particularly among medical men, whom it chiefly concerns, are directed to the subject, and important results may be looked for. A vast number of facts have now been carefully observed and recorded, and to a certain degree, have been classified; and perhaps some master genius may soon arise, to shew that a very few simple truths connect the whole, as NEWTON shewed with respect to the inferior classifications in physics, when he detected the general laws of *inertia* and *gravity*. The Science of *Life* is divided into *animal* and *vegetable Physiology*.

Mind.—The most important part of all science, is the knowledge which man has obtained of the laws which govern the operations of his own MIND. This department stands eminently distinct from the others, on several accounts. Unlike that of *organic life*, which could not be understood until physics and chemistry had been previously investigated, this attained extraordinary perfection in a very early age, when the others had scarcely begun to exist. We need only refer to the writings of the Greek philosophers, in proof of the assertion. The brilliant discoveries, however, were reserved for the moderns, as will occur to most readers, on perusing in the table below the divisions of the subject, and recollecting the honoured names which are now associated with each. It is truly admirable to see the modern analysis deducing from a few simple laws of mind, all the subordinate departments, just as it deduces mechanics, hydrostatics, &c., from the laws of physics.—It is to be remarked, that the laws of mind which man can discover by reason, are not laws of independent mind, but of mind in connexion with body and influenced by the bodily condition. It has been believed by many, that the nature of mind separate from body, is to be at once all-knowing and intelligent. But mind connected with body, can only acquire knowledge slowly, through the bodily organs of sense, and more or less perfectly, according as these organs and the central brain are perfect. A human being born blind and deaf, and therefore, remaining dumb, as in the extraordinary case of the boy Mitchell, which excited so much attention some years ago, grows up to resemble an automaton: and an originally mis-shapen or deficient brain causes idiocy for life. Childhood, maturity, dotage, which have such differences of bodily powers, have corresponding differences of mental faculty; and as no two bodies, so no two minds as manifested externally, are quite alike. Fever or a blow on the head will change the most gifted individual into a maniac; and most cases of madness and of eccentricity can now be traced to a peculiar state of the brain.—Man has a conviction inseparable from his very being, that his soul is something distinct from his body, and awaiting other destinies: but, independently of Revelation, his notions on the subject remain very vague, as is shewn in the laborious reasonings of the ancient heathen philosophers.

Quantity.—Many of the facts and laws of physics, chemistry, and life are expressed in terms of QUANTITY, as when we say, that the force of attraction between two bodies diminishes in a certain proportion, as their distance increases. Hence arises the necessity of having a set of fixed measures or standards, with which to compare all other quantities. Such measures have been adopted; and the rules for applying them to all possible cases, and for comparing all kinds of quantities with each other, constitute a body of science, called the *Science of Quantity*, or Mathematics. It may be considered as a fifth and supplementary department of human science. Some of its subdivisions are noted in the table below.

Supposing *description*, or *Natural History* to be studied along with the different parts of the *System of Science* sketched in the table, there will be included the whole knowledge of the universe which man can acquire by the exercise of his own powers; that is to say, which he can acquire independently of *Revelation*. And all his arts are founded on this knowledge—some of them on a single part, as Physics, some on two or more parts. The art of medicine requires a comprehensive knowledge of the whole.

TABLE OF SCIENCE.

1. Physics.
Mechanics,
Hydrostatics,
Hydraulics,
Pneumatics,
Acoustics,
Optics,
Electricity,
Astronomy,
&c.

3. Life.
Vegetable Physiology,
Botany,
Horticulture,
Agriculture,
&c.

Animal Physiology,
Zoology,
Anatomy,
Pathology,
Medicine,
&c.

2. Chemistry.
Simple Substances,
Mineralogy,
Geology,
Pharmacy,
Brewing,
Dyeing,
Tanning,
&c.

4. Mind.
Intellect,
Reasoning,
Logic,
Language,
Education,
&c.
Active Powers.
Emotions and Passions,
Justice,
Morals,
Government,
Political Economy,
&c.
Natural Theology.

5. Science of Quantity.
Arithmetic,
Algebra,
Geometry,
&c.

From the mutual dependence of the different sciences, as explained in the preceding paragraphs, it follows, that "The Table" exhibits the order in which they should be methodically studied, so as to prevent repetitions and anticipations, and to diminish as much as possible the labour of acquirement.

Every man may be said to begin his education, or acquisition of knowledge, on the day of his birth. Certain objects, repeatedly presented to the infant, after a time, are recognized and distinguished. The number of objects thus known gradually increases, and from the constitution of the human mind, they are soon associated in the recollection, according to their resemblances, or obvious relations. Thus sweetmeats, toys, articles of dress, &c. soon form distinct classes in the memory and conceptions. At a later stage, but still very early, the child distinguishes readily between a stone or *mineral* mass, a *vegetable* and an *animal*; and thus his mind has already noted the three great classes of natural bodies, and has acquired a certain degree of acquaintance with *Natural History*. He also soon understands the phrases "a falling body," "the force of a moving body," and has therefore a perception of the great physical laws of gravity and inertia. Having, then, seen sugar dissolved in water, and wax melted about the wick of a burning candle, he has learned some phenomena of Chemistry. And having observed the actions of the domestic animals, and of the persons about him, he has begun his acquaintance with Physiology and the Science of Mind. Lastly, when he has learned to count his fingers and his sugar-plums, and to judge of the fairness of the division of a cake between himself and his brothers, he has advanced into Arithmetic and Geometry.—Thus within a year or two, a child of common sense has made a progress in all the great departments of human science: and in addition, has learned to name objects, and to express feelings, by the arbitrary sounds of language. Such, then, are the beginnings or foundations of knowledge on which future years of experience, or methodical education, must rear the structure of more considerable attainments befitting the various conditions of men in a civilized community.

From the preceding pages, it appears that the *Science of Nature* may be considered as a continuous and closely connected system or history, which, to be clearly understood, must be studied according to the natural order of its parts, just as any common history must be read in the natural order of its paragraphs. But so little has this truth been known, or at least, acted upon in general, that perhaps no other human plans formed with one object, have been so dissimilar and inconsistent as the common plans of education. The greater part of the deviations from the arrangement sketched above, must appear so obviously errors, to any person who has at all investigated the subject, that it is unnecessary here to speak of them particularly; but we must notice the question as to whether *Mathematics* and *Logic* should come at the beginning or termination of a course of scientific study.

Mathematics are at present generally made the beginning of the study, and the reason assigned is, that scarcely any object in Physics, Chemistry, or Organic Life can be described without referring to *quantity* or *proportion*, and therefore, without using mathematical terms. Now this is true, but it is equally true, that the mathematical knowledge, acquired by every individual in the common experience of childhood, at the same time with the commencements of Physics, Chemistry, and Life, as already explained, is perfectly sufficient to enable students to understand all the great laws of nature. Few persons in civilized society are so ignorant, as not to know that a square has four equal sides, and four equal corners or angles, and that every point in the circumference of a circle is at the same distance from the centre; now these truths, with others similar, learned in the same way, form a very important body of mathematical knowledge, and a passport to the understanding of all the general laws of nature. When these laws are once comprehended, and the mind has become familiar with many of the material realities of the universe, the study of the higher mathematics becomes exceedingly interesting, because useful applications of the various truths are immediately perceived: and a good course on mathematics is made to include higher courses on Physics, Chemistry, and

Life. But most persons find attention to pure preliminary mathematics as irksome as the study of a mere alphabetical dictionary of the words of a language where it is not allowed to read the compositions written in that language. This explains why so small a proportion of students become good mathematicians, if taught in the common way: and why, where pure mathematics are made the avenue to Natural Philosophy, this also is so much neglected.—Abstract Logic, which is a branch of mental Philosophy, as a preliminary study, is of a piece with Abstract Mathematics, and has been commended on similarly erroneous grounds.

The notions on education existing in the world until recently, have been as erroneous with respect to the comparative importance of different branches of knowledge as with respect to the order of study. Thus at many of our famed schools, and even universities, the attention has been directed almost solely either to *Languages* and *Logic*, or to *Abstract Mathematics;* the preceptors seeming to forget that these objects have no value but in their application to *Physics*, *Chemistry*, *Life*, and *Mind*. This mode of proceeding is just as if a man, to whom permission were given to enter and possess a magnificent garden, on condition of his procuring a key to open the gate, and measures of all kinds to estimate the riches contained within, should waste his whole life on the road in polishing one key or procuring others, and in preparing a multiplicity of measures; thus forgetting altogether on what account the key and the measures had any value. This and many similar errors arise, from men not being in general taught to carry in their minds a clear conception of the whole field of human knowledge, and thence of the comparative importance of the different subdivisions. He whose view is bounded by the limits of one or two small departments, will probably have very false ideas even of them, but he certainly will of other parts, and of the whole; so as to be constantly exposed to commit errors hurtful to himself or to others. His mind is to the wellordered mind of a properly educated man, what the crooked and mis-shapen body of a mechanic, confined to certain actions and attitudes, is to the most perfect form of the human species.

By arranging science according to its natural relations, and therefore, so as to avoid all repetitions and anticipations, a very complete system might be exhibited in small bulk, *viz.* in five volumes, of which the separate titles would be *Physics*, *Chemistry*, *Organic Life* or *Physiology*, *Mind*, and *Measures* or *Mathematics*. From such works, with less trouble than it now costs to obtain familiarity with a new language, a man might obtain a general acquaintance with science. And such is the close relation of the sciences among each other, that a man may generally acquire consummate skill in any one branch more easily, by first studying the whole in a general way, and then applying particularly to that branch, than by fixing the attention from the beginning more exclusively. The study of Anatomy thus becomes very easy to him who has first studied Physics.

The book of five volumes would merit the name of the *Book of Nature.* To have all the perfections of which it is susceptible, it can be looked for only from academies of science or associations of learned men. At present a great part of human labour, and genius, and existence, are wasted for want of such a work. Students, from having no direction, or only that which is faulty, apply to subjects in unnatural order, and therefore neither well understand nor remember what they read. Many who study various works on the same subject, that the inaccuracies or omissions of one may be corrected by the others, are confounded by the difference of arrangement in the different works, and seldom get clear notions. The vast increase of labour also occasioned by ill-ordered study, discourages and disgusts the greater part of them, &c. If, however, by the care of government or of universities, the *five volumes* were in existence, and their authoritative character known, the spirited youth, when he began his studies, from seeing at once the limited extent of his task, would enter upon it with the alacrity and confidence which would soon make him master of the field. During the complete review also of science and art then made, each would be able better to choose the occupation in life suited to his powers and character. The minds of persons generally, becoming thus fully informed in the season of their young vigour and elasticity, might set out on their flight in quest of new discoveries from greater elevations than their predecessors, and might be expected to attain still nobler objects. The finest enterprizes of human genius have been planned and commenced, and often accomplished in early youth. There would be this further important consequence, that persons being made so soon to understand the beauty and grandeur of creation, would early acquire an elevation of mind, which would render them less likely afterwards to lapse into those sinks of idleness and vice which now receive and destroy so many.

Were such elementary treatises once in existence, they might be maintained complete by an annual incorporation of new discoveries. And by being furnished with correct and copious references, they might be made an index to the whole existing mass of knowledge. The *Book of Nature* would be of more value to the world than even another Newton or Watt, for it would convert the minds of millions into intellectual organs of advancement, among whom there would be many as highly endowed by nature as were even Newton or Watt.

The increased facility of acquirement here contemplated, would by no means put an end to the distinctions among men of *learned* and *unlearned*, as some might fear. The plan provides for more sound and useful information in the first grades of study, the influence of which would be felt through all; but it leaves the unlimited fields of mathematical research, of Belles Lettres, of Natural History, &c. as open as ever to the enterprises of leisure, and of peculiar taste. It is true, that the whole intellect of the community would be awakened, and that existing talent would every where be elicited, and would generally reach the stations where it could be most useful; but this would be for the profit of all the members of the state.

In the course of the preceding disquisition, we have seen that *Physics* or *Natural Philosophy*, the subject of the present volume, is fundamental of the other parts, and therefore, is that of which the knowledge is the most indispensable. Bacon very truly calls it "the root of the sciences and arts." That its importance has not been marked by the place which it has held in common systems of education, is owing chiefly to the misconception already spoken of and refuted, that a knowledge of technical mathematics was a necessary preliminary; and to an opinion, that the degree of acquaintance with Physics which all persons acquire by common experience, is sufficient for common purposes:—now it is true, that the toys of childhood, as the windmill, ball, syphon tube, and a hundred others, furnish so many examples of the laws of Physics, and may well be called a philosophical apparatus; but they give information which is exceedingly vague, and not at all such as is now absolutely requisite in the practice of many of the arts.—If the study of Physics be so easy, then, as now appears, and so important as we shall try still farther to shew, there can be no excuse for neglecting it.

The greatest sum of knowledge acquired with the least trouble, is that which comes with the study of the few simple truths of Physics. To the man understanding these, very many phenomena, which, to the uninformed appear prodigies, are only beautiful illustrations of his previous general knowledge; and this he carries about with him, not as an oppressive weight, but as the charm which supports the weight of other knowledge, and enables him to add to his valuable store, every new fact of consequence which may offer. With such a principle of arrangement, knowledge, instead of resembling loose stones or rubbish thrown together in confusion, becomes a noble edifice, of correct proportions and firm contexture, which is acquiring greater strength and consistency with the experience of every succeeding day. It has been a prejudice that persons thus instructed in general laws, have their attention too much divided, and can know nothing perfectly. The very reverse, however, is true; for general knowledge renders all particular knowledge more clear and precise. The ignorant man may be said to have charged his hundred hooks of knowledge, to use a rough simile, with single objects, while the informed man makes each support a long chain, to which thousands of useful things are attached. The laws of Philosophy may be compared to keys which give admission to the most delightful gardens that fancy can picture; or to a magic power, which removes a veil from the face of the universe, and discloses endless charms which ignorance sees not. The informed man, in the world, may be said to be always surrounded by what is known and friendly to him, while the ignorant man is as one in a land of strangers and enemies. A man may read a thousand volumes of ordinary books as agreeable pastime, leaving vague impressions; but he who, through general laws, studies the *Book of Nature*, converts the great universe into the material of a sublime history which tells of God, and which may worthily occupy his attention to the end of his days.

We have said already, that the laws of Physics govern the great *natural* phenomena, of Astronomy, the tides, winds, currents, &c. We will now mention some of the *artificial* purposes to which man's ingenuity has made the same laws subservient. Nearly all that the civil engineer accomplishes, ranges under the head of Physics. Let us take, for instance, the admirable specimens scattered over the British Isles.—The numerous canals for inland traffic; the docks to receive the riches of the world, pouring towards us from every quarter; the many harbours offering safe retreat to the storm-driven mariner; the magnificent bridges which every where facilitate intercourse; hills bored through to open roads for commerce by canal-boats or carriages, and the continued tracks, sometimes carried across vallies or above rivers, so that here and there the singular phenomenon is seen of one vessel sailing directly over another; vast tracks of swamp or fen-land, drained, and now serving for agriculture. In Holland, great part of the country stolen from the sea, acknowledges the same almost creating power; and there rich cities, and an extended garden, now smile, where, as related by Cæsar, were formerly bogs and a dreary waste. And who can contemplate with indifference the noble light-house, rearing its head amidst the storm, while the dweller within trims his lamp in safety, to guide his endangered fellow-creature through the perils of the storm.

As a striking picture, let us consider, that in situations where the rude savage formerly beheld the cataract falling among the rocks, and the wind bending the trees of the forest, and sweeping the clouds along the mountain's brow, or whitening the face of the ocean, and regarded these phenomena with awe or terror, as marking the agency of some mighty power which might destroy him;—in the same situations now, his informed son, who works with the laws of nature, can lead the waters of the cataract by sloping channels to convenient spots, where they are made to turn his mill-wheel, and do his multifarious work. The rushing winds also, he makes his servants, by rearing the broad-vaned windmill in their course, which then performs a thousand offices for its master, man. And the breezes which whiten ocean, are caught in his expanded sails, and are made to waft their lord and his treasures across the deep for his pleasure, or his profit.

In Architecture Physics is also supreme, and has ruled the construction of the temples, pyramids, domes, spires, towers, and palaces which adorn the earth.

As to machinery generally, Physics is the guiding light.

We may mention the mighty steam-engine; machines for spinning and weaving; for moulding other bodies into various shapes, yea, even iron itself, as if it were plastic clay; windmills, and watermills, and wheel carriages; the plough and implements of husbandry; gunnery, and the art of war; the implements of our intellectual arts, of printing, drawing, painting, sculpture, &c.; our musical instruments; our optical and mathematical instruments, and a thousand others.

And besides all these, and other uses, Physics is an important foundation of the healing art. The medical man, indeed, is the engineer pre-eminently; for it is in the animal body that true perfection and the greatest variety of mechanism are found. Where is there, to illustrate *Mechanics*, a system of levers, and hinges, and moving parts, like the limbs of an animal body; where such an *hydraulic* apparatus, as in the heart and blood-vessels; such a pneumatic apparatus, as in the breathing chest; such *acoustic* instruments, as in the ear and larynx; such an *optical* instrument, as in the eye; in a word, such mechanical variety and perfection, as in the whole of the visible anatomy! All these structures, the medical man, of course, should understand, as a watchmaker knows the parts of the machine about which he is employed. The latter, unless he can discover where a pin is loose, or a wheel injured, or a particle of dust adhering, or oil wanting, &c., would ill succeed in repairing an injury: and so also of the ignorant medical man in respect to the human body. Yet will it be believed, that there are medical men who neither understand mechanics, nor hydraulics, nor pneumatics, nor optics, nor acoustics, beyond the merest routine; and that systems of medical education are put forth at this day which do not even mention the department of *Physics!*

That such is the case, furnishes illustration of what is stated in the beginning of this essay; that the sciences and arts are progressive, and that perfect methods of education must arise gradually, like all other things of human contrivance. It is within the recollection of persons now living, that political economy was discovered to be a grand foundation of the art of government, and a security against many national misfortunes common in former times, yea, even famine and war. And the day is not distant, when the members of the medical profession generally will understand how much the correct knowledge of animal structure and function, and of many remedies, must depend on precise acquaintance of Physics.

Besides the strictly professional matters, contained in the medical sections of the present work, there are many others scattered through it which much interest the medical man; such as the subjects of *meteorology*, *climate*, *ventilation* and *warming* of dwellings, *specific gravities*, &c. &c. But, indeed, what part of Natural Philosophy is not interesting to a medical man, since the whole is becoming every day more and more a part of a liberal education. In our cities, and even in an ordinary dwelling-house now, a man is surrounded by miracles of mechanic art, and with his proud reason, is he to use these, as careless of how they are produced, as a horse is of how the corn falls into his manger! A general diffusion of knowledge is now elevating the human character in all ranks of society, and making men who reflect feel how different their condition is from that of their remote forefathers. These, generally forming small states or societies, had few relations of amity with surrounding tribes, and their thoughts and interests were confined very much within their own little territories and rude habits. In succeeding ages, they found themselves belonging to larger communities, as when the English heptarchy was united; but still remote kingdoms and quarters of the world, were of no interest to them, and were often totally unknown. But every one now sees himself a member of one vast civilized society, which covers the whole face of the earth; and no part of the earth is indifferent to him. A man of small fortune in England, may cast his regards around him, and say with truth and exultation, "I am lodged in a house which affords me conveniencies and comforts which a king could not command some centuries ago. There are ships crossing the seas in every direction, to bring me what is useful to me from all parts of the earth. In China, men are gathering the tea-leaf for me; in America, they are planting cotton for me; in the West-India islands, they are preparing my sugar and my coffee; in Italy, they are feeding silk-worms for me; in Saxony, they are shearing the sheep to make me clothing; at home, powerful steam-engines are spinning and weaving for me, and making cutlery for me, and pumping the mines, that minerals useful to me may be procured. My patrimony was small, and yet I have post-coaches day and night running on all the roads to carry my correspondence; I have roads, and canals, and bridges to bear the coal for my winter fire; nay, I have protecting fleets and armies around my happy country, to secure my enjoyments and repose. Then, I have editors and printers who daily send me an account of what is going on throughout the world, among all these people who serve me. And in a corner of my house, I have BOOKS! the miracle of all my possessions, more wonderful than the wishing-cap of the Arabian tales; for they transport me instantly, not only to all places, but to all times. By my books, I can conjure up to vivid existence before me, all the great and good men of antiquity; and, for my individual satisfaction, I can make them act over again the most renowned of their exploits. The orators declaim for me; the historians recite; the poets sing: in a word, from the equator to the pole, and from the beginning of time until now, by my books, I can fly whither I please.—This picture is not overcharged, and might be much extended; and such is the miracle of God's goodness and providence, that each individual of the civilized millions that cover the earth, may have nearly the same enjoyments as if he were the single lord of all.

Reverting to the importance of Natural Philosophy as a general study, it may be remarked, that there is no occupation which so much strengthens and quickens the judgment. This praise has usually been bestowed on Mathematics; but if we reflect, that Natural Philosophy comprehends Mathematics, and gives tangible and pleasing illustrations of the abstract mathematical truths, so as to relieve the tension of mind, which to many persons is painful; it seems entitled to still higher praise. A man whose mental faculties have been sharpened by familiarity with these exact sciences, either separate or combined, and who has been engaged, therefore, in contemplating *real relations*, is more likely to discover truth in other questions, and can better defend himself against sophistry of every kind. We cannot have clearer evidence of this, than in the history of the sciences, since the Baconian method of philosophising by induction, took place of the visionary *hypotheses* of preceding times. Until then, even powerful minds did not recoil from the most absurd theories on all subjects. Astronomy was mixed with Astrology; Chemistry with Alchemy; Physiology with the singular hypotheses which preceded the discovery of the circulation of the blood.—Even religion itself, in various ages and countries, has felt the influence of the state of the public mind as to solid attainments. To a man with the knowledge of nature which we now possess, the fables and licentious abominations of the Greek or Roman theologies are shocking indeed; as are also the religions of the God of Fire in China, or of Vishnoo in India, or of Mahomet's imposture and pretended miracles, &c.—But the enlightened Christian minister earnestly recommends the study of nature; first because from contemplating the beauty of creation discovered by general philosophy, with the wisdom and benovolent design manifest in all its parts, there spring up in every undepraved mind those feelings of delight and gratitude, which constitute the adoration of natural religion, and form, as shewn by Dr. Paley, and other writers on Natural Theology, a fit foundation for the sublime doctrine of immortality:

and secondly, because Revelation must be proved by the miracles which accompanied its establishment; and to enable men to distinguish between miracles and the usual course of nature, a perfect knowledge of that course, or of Natural Philosophy, is absolutely essential. All the false religions of antiquity were founded on, and upheld by pretended miracles. As regards the question of immortality, even independently of Revelation, no man who contemplates the order and beauty of the material world, and who sees the hideous deformities of the moral world—where vice so often triumphs, and modest virtue pines and dies—can for a moment believe them to be the work of the same author, unless there be an hereafter of retribution; and feeling that eternal justice requires another state for man, he embraces with delight the cheering promises of Christianity. There have been, however, at various times, even among Christians, sincere, but weak or ill-informed men, who decried the study of the natural sciences, as inimical to true religion—as if God's ever-visible and magnificent revelation of his attributes in the structure of the universe could be at variance with any other revelation !—Where considerable knowledge of nature exists, debasing and gloomy superstition must cease. It is not the abject terror of a slave which is inspired by contemplating the majesty and power of God, displayed in his works, but a tender regard, like that which leads a favoured child to approach with confidence a wise and indulgent parent.

It now only remains for the author to say a few words with respect to the present volume. With his belief, as stated in a former page, that ere long, associations of able men will be employed to frame and connect the parts of an elementary *Book of Nature*, he adds this to the already existing treatises on Physics, merely with the hope that it may serve usefully for a time, and may then furnish its share of hints for the composition of one more complete. He was originally led to the undertaking by the hope, that he might be able to supply the important desideratum in medical literature of a treatise on *Medical Physics*: but perceiving, as he proceeded, that the preliminary investigation of *General Physics* required to suit the work for medical readers, would have to be nearly as extensive as if it were for general readers; he determined to make his work as complete, and as extensively useful, as possible. He has been encouraged during his labour, by the belief, that the growing light of science which now exhibits more clearly the natural relations of the different departments of study, as is attempted to be pourtrayed in the preceding pages, might enable him to avoid some of the defects of former elementary treatises, and to add some features of novelty and improvement to his own. But he is still conscious how very far his work is from having the perfection of which, even in the present state of knowledge, such a work is susceptible. An elementary treatise on Natural Philosophy should be characterized—by requiring in the reader no previous information, but a knowledge of the language in which it is written, and the commonest experience of the world; by having an arrangement of the subjects, as scientific or methodical, as in a strictly mathematical treatise, yet without using a single term of technical mathematics; by the general principles being illustrated in all cases, rather by bringing before the reader interesting natural phenomena, than artificial experiments and dry abstract reasonings; by containing nothing of so little interest as to be readily forgotten; by the book being calculated for general readers, and not for those of one profession or class; by embracing such an account of recent improvements, as to foster the spirit which leads to further study and advancement, &c.—In composing the *general* chapters of the work, the author has been guided by these considerations, as far as his ability and leisure would permit. The sections on *Animal Physics* were, of course, written for medical men; and a great service will be rendered by the work, if it only awakens them to a just sense of the importance of Physics, as one of the foundations of their art. But, even for general readers, there are few parts of these sections, which the author would exclude. There is nothing more admirable in nature than the structure and functions of the human body, and there are many reasons why no liberal mind can be careless of the study. The details here are not more anatomical, than Paley's illustrations from the animal economy, contained in his *Natural Theology*.—From the attempt in this work to compress into the smallest possible space, the greatest possible sum of scientific information, few historical details have been admitted, whether relating to the distinguished men, who have benefited the world, as authors or inventors, or to the history of the progress of science. Such details form an interesting, but distinct branch of study. With the concluding part of the work there will be given a list of the best authors who have treated on the various subjects.

The author must not conclude without observing, that no treatise on Natural Philosophy can save to the reader of it, the necessity of attendance on experimental lectures or demonstrations. Things that are seen, and felt, and heard, that is, which operate on the external senses, leave on the memory, much stronger, and more correct impressions, than where the conceptions are produced merely by verbal description, however vivid. And no man has ever been remarkable for his knowledge of Physics, Chemistry, or Physiology, who has not had *practical familiarity* with the objects. With reference to this familiarity, persons who take a philanthropic interest in the affairs of the world, must observe with much pleasure, the now daily increasing facilities of acquiring useful knowledge, afforded by the scientific institutions that are formed and forming, through this kingdom, and, indeed, through most civilized nations.

Those of the readers of this work, who know the manner of a medical man's life, will not be disappointed by missing here the minute accuracy and polish found in the productions of more leisurely writers; but amidst all the interruptions and anxieties inseparable from his employments, the author hopes, that his omissions and inelegancies, are not mixed with many considerable errors. He would feel greater solicitude, as to the reception of his work, if he did not know that the subjects embraced in it are exceedingly interesting in themselves, so that when treated with ordinary clearness and precision, they never fail to please.

Bedford Square,
1*st March*, 1827.

1st. Atom (a Greek word signifying *that which cannot be farther divided*) means an exceedingly minute resisting particle. The visible universe is built up of such particles, held together by an influence called

2d. Attraction, which word implies that all the atoms, whether separate or already joined into masses, tend towards each other, and all other masses, with force proportioned to their various proximity.

3d. Repulsion means that under certain known circumstances, as of heat diffused among the particles, their *attraction* is countervailed or resisted, and they tend to separate with force proportioned to their proximity.

4th. Inertia expresses the fact that the atoms, as regards motion, have a *stubbornness* about them which tends always to keep them in their existing state whatever it may be. Hence bodies neither acquire motion, nor lose motion, nor bend in motion, but in exact proportion to the force applied.

A person comprehending fully the import of these four words, may predict or anticipate correctly very many of the facts and phenomena, which the extended experience of a life can display to him. To give the reason or explanation of any fact, means only to shew its accordance with a general truth or principle; and it will be found that this volume is merely an enumeration of a vast mass of the most important facts or phenomena of nature and art, classified so as to be explained by the four physical truths, and so as mutually to illustrate each other. They will be distributed under the following five heads or divisions.

CHAPTER I.

SOMATOLOGY and DYNAMICS (from Greek words signifying *a discourse on bodies* and *force or power*: —the four truths made to explain generally the constitution of masses, and the motions going on among them.

CHAPTER II.

MECHANICS (from the Greek word signifying a machine)—the four truths explaining the peculiarities of state and motion among *solid* bodies.

CHAPTER III.

HYDRODYNAMICS (from Greek words signifying *water* and *force*) :—the truths explaining the peculiarities of state and motion among *fluid* bodies.

Section 1. HYDROSTATICS (*water at rest*).
——— 2. PNEUMATICS (*air phenomena*).
——— 3. HYDRAULICS (*water or fluid in motion*).
——— 4. ACOUSTICS (*phenomena of sound and hearing*.

CHAPTER IV.

The truths aiding to explain the more recondite phenomena of IMPONDERABLE SUBSTANCE under the heads of

Section 1. CALORIC or *heat*.
——— 2. OPTICS, *light*.
——— 3. ELECTRICITY, from the Greek word signifying *amber*; for the electric light was first obtained from amber.
——— 4. MAGNETISM.

CHAPTER V.

ASTRONOMY—*phenomena of the heavens.*

Under each chapter will be ranged the illustrations afforded by the animal economy. ANIMAL AND MEDICAL PHYSICS.

As no man can understand a subject of which he does not carry a distinct outline in his mind, the reader of this volume is recommended to study the general *synopsis*, and the *analyses* placed at the heads of the *chapters* and *sections*, until the memory be strongly impressed with them. The *synopsis* gives a general view of the subject, like what a traveller may obtain of a new country from a lofty central peak, that commands the whole. The *analysis* gives a general view of one division, like what the traveller has of a portion of the country from a lower summit; and the "*heads*" placed thus between inverted commas may be figured as commanding single vallies or fields.

CHAPTER I.

THE FOUR FUNDAMENTAL TRUTHS MINUTELY EXAMINED, AND USED IN A GENERAL WAY, TO EXPLAIN, FIRST, THE NATURE OR CONSTITUTION OF THE MATERIAL MASSES WHICH COMPOSE THE UNIVERSE, AND SECONDLY, THE MOTIONS OR PHENOMENA GOING ON AMONG THESE.

SECTION I.—ON THE CONSTITUTION OF MASSES.

ANALYSIS OF THE SECTION.

The visible universe is built up of very minute indestructible, or material atoms, which, by mutual attraction, cohere or cling together in masses of various forms and magnitudes. The atoms are more or less close, according to the quantity or repulsion of heat among them, and hence arise the three remarkable forms in the masses, of solid, liquid, and air, which mutually change into each other with change in the quantity of heat. Certain modifications of attraction and repulsion produce the subordinate peculiarities of crystal, dense, hard, elastic, brittle, malleable, ductile, and tenacious.

" *Minute Indestructible Atoms.*"*

THE smallest portion of any substance which the human eye can perceive, is still a mass of many ultimate atoms or particles, which may be separated from each other, or newly arranged, but which cannot individually be hurt or destroyed.

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* The different heads or titles, which appear thus between inverted commas throughout the work, are the successive portions of the *Analyses*, detached for separate consideration: and the reader is particularly requested to re-peruse the analysis at the several interruptions, that he may have constantly before him that clear view of the general relations among the different parts of the subject, which is essential to a perfect understanding of it.

A particle of powdered marble, hardly visible to the naked eye, still appears to the microscope a block susceptible of indefinite division; and, when broken by fit instruments, until the microscope can hardly discover the separate particles of the fine powder, these may be yet farther divided, by dissolving them in an acid; until the whole become absolutely invisible, as part of a transparent liquid.

A small mass of gold may be hammered into thin leaf, or drawn into fine wire, or cut into almost invisible parts, or liquefied in a crucible, or dissolved in acid, or dissipated by intense heat into vapour; yet, after any and all of these changes, the atoms can be collected again, and the original gold can be exhibited in its pristine state, without the slightest diminution or change. And all the substances or elements of which our globe is composed, may thus be cut, torn, bruised, ground, &c. a thousand times, but are always recoverable as perfect as at first.

And, with respect to delicate combinations of these elements, such as we see in animal and vegetable substances, although it be beyond human art, originally to form, or to imitate many of them, still, in their decomposition and apparent destruction, the accomplished chemist of the present day does not lose a single atom. The coal which burns in his apparatus, until only a little ash remains behind, or the wax-taper which seems to vanish altogether in flame, or the portion of animal flesh, which putrifies, and gradually dries up and disappears: all these phenomena are now proved to be only changes of connexion and arrangement among the indestructible ultimate atoms; and the chemist can offer all the elements again, mixed or separate, as desired, for any of the useful purposes to which they are severally applicable. When the funeral piles of the ancients, with their charge of human relict, appeared to be wholly consumed, and left the idea with survivors that no base use could be made, in after time, of what had been the material dwelling of a noble or beloved spirit; the flames had only, as it were, scattered the everlasting blocks of which a former edifice had been constructed, but which were soon to serve again in new combinations.

"*Minute.*"

The following are interesting particulars in the arts or in nature, helping the mind to conceive how minute the ultimate atoms of matter must be.

Goldbeaters, by hammering, can reduce gold to leaves so thin, that 282,000 must be laid upon each other to produce the thickness of an inch; yet those leaves are perfect, or without holes, so that one of them laid upon any surface, as in gilding, gives the appearance of solid gold. They are so thin, that if formed into a book, 1,500 would only occupy the space of a single leaf of common paper; and an octavo volume of an inch thick would have as many pages as the books of a well-stocked ordinary library of 1,500 volumes with 400 pages in each.

Still thinner than this is the coating of gold, upon the silver wire of what is called gold lace, and we are not sure that such coating is of only one atom thick.

Platinum and silver can be drawn into wire much finer than human hair.

A grain of blue vitriol, or carmine, will tinge a gallon of water, so that in every drop, the colour may be perceived.

A grain of musk will scent a room for twenty years, and will have lost little of its weight.

The carrion crow smells its food many miles off.

A burning taper uncovered for a single instant, during which it does not lose 1,000th of a grain, would fill with light a sphere four miles in diameter, so as to be visible in every part of it.

The thread of the silk-worm is so small, that many of them are twisted together to form our finest sewing thread; but that of the spider is smaller still, for two drachms of it by weight, would reach from London to Edinburgh, or 400 miles.

In the milt of a cod-fish, or in water in which certain vegetables have been infused, the microscope discovers animalcules, of which many thousands together do not equal in bulk a grain of sand; and yet, nature with a singular prodigality, has supplied many of these with organs as complex as those of the whale or elephant; and their bodies consist of the same substances, or ultimate atoms, as that of man himself. In a single pound of such matter, there are more living creatures than of human beings on the face of this globe. What a scene has the microscope opened to the admiration of the philosophic inquirer!

Water, mercury, sulphur, or, in general, any substance, when sufficiently heated, rises as invisible vapour or gas; that is, it is reduced to the aeriform state. Great heat, therefore, would cause the whole of the material universe to disappear, and the most solid bodies, to become as invisible and impalpable as the air we breathe. Few have contemplated an annihilation of the world more complete than this.

"*Matter*."

The inconceivable minuteness of ultimate atoms, as shewn above, has led some inquirers to doubt whether there really be *matter*; that is, whether what we call substance or matter, have existence or not. In answer to this, besides the proofs of indestructibility already mentioned, and which seem conclusive, it has been usual to adduce the fact, that every kind or portion of matter, obstinately occupies some space, to the exclusion of all other matter from that particular space. And this occupancy of space, is the simplest and most complete idea, which we have of material existence. The awkward word *impenetrability* has been used to express it, as applied to the individual atoms of matter. The following are elucidations.

We cannot push one billiard ball into the substance of another, and then a second, and then a third, and so on; or the material of the universe might be absorbed in a point.

A lump of iron on a support will resist the weight of thousands of pounds laid upon it, and pressing to descend into its place; and although a very great weight might crush or break it into pieces, it could not annihilate one particle. In a forcing pump, or in Bramah's water press, millions of pounds cannot push the piston down, unless the water below it be allowed to escape.

A weight laid upon bladders full of air is supported in the same manner.

A glass tube, left open at bottom, while the thumb closes the top, if pressed from air into water, does not fill with water, because the air contained in it resists; but if the air be allowed to escape by removing the thumb from the top, it fills immediately to the level of the water around it. A goblet or basin pushed into water in the same way, with the mouth downwards, does not fill with water for the like reason; and if the goblet be inverted over a little floating lighted taper, this will continue to float under the vessel, and to burn in the contained air, however deep in the water it may be carried: being a light below water, and emblematic of the living inmate of a diving bell, which is merely a larger goblet with a man instead of a candle.

"*Mutual Attraction*" (*see the analysis, page 5th*).

Any visible mass or lump of matter, then, as of metal, salt, sulphur, &c., we know to be really a collection of dust, or minute atoms, which something causes to cohere or cling together; yet there are no hooks to connect them, nor nails, nor glue, and the connexion may be broken a thousand times, by processes of art, or otherwise, but is always ready to form again, and the property is no more destroyed by interruption, than the weight of a thing is destroyed by its being lifted often from the ground; or the attraction of a magnet and mass of iron by their being often separated. The phenomena of attraction or repulsion, when at considerable distances particularly, are among the most extraordinary things which the human mind has to contemplate; and although the manner or laws of these actions are now well understood, they are ultimate facts that admit of no explanation in the present state of science. The general nature and importance of attraction will be gathered from the following facts.

Logs of wood floating in a pond approach each other, and afterwards remain in contact.

The wreck of a ship, in a smooth sea after a storm, is often seen gathered into heaps.

Two bullets or plummets suspended by strings near to each other, are found by the delicate test of the torsion balance, to attract each other, and therefore not to hang quite perpendicularly.

A plummet suspended near the side of a mountain, inclines towards it, in a degree proportioned to its magnitude; as was ascertained by the well-known trials of Dr. Maskeleyne near the mountain Skehalion, in Scotland.

And the reason why the plummet tends much more strongly towards the earth than towards the hill, is only that the earth is larger than the hill.

And at New South Wales, which is a point on our globe nearly opposite to England, plummets hang and fall towards the centre of the globe, exactly as they do here, so that they are hanging up and falling towards England, and the people there are standing with their feet towards us. Weight, therefore, is merely general attraction acting every where.

But it is owing to this general attraction that our earth itself is a globe. All its parts being drawn towards each other, that is towards a common centre, the mass assumes the spherical or rounded form.

And the moon also is round, and all the planets are round; the glorious sun, so much larger than all these, is round: proving that all must at one time have been fluid, and that they are all subject to the same law.

Other instances of roundness from this cause are—the particles of a mist or fog floating in air—these, mutually attracting and coalescing into larger drops, and forming rain—dew drops—water trickling on a duck's wing—the tear dropping from the cheek—drops of laudanum—globules of mercury, like pure silver beads, coalescing when near, and forming larger ones—melted lead allowed to rain down from an elevated sieve, which cools as it descends, so as to retain the form of its liquid drops, and becomes the spherical shot-lead of the sportsman.

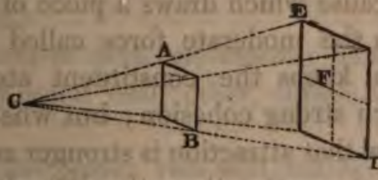
The cause of the extraordinary phenomenon, which we call attraction, acts at all distances. The moon, though 240,000 miles from the earth, by her attraction, raises the water of the ocean under her, and forms what we call the tide.

The sun, still farther off, has a similar influence; and when the sun and moon act in the same direction, we have the spring tides.

The planets, those apparently little wandering points in the heaven, yet affect by their attraction, the motion of our earth in her orbit, quickening it when she is approaching them, retarding it when she is receding.

The *attraction is greater* the nearer the bodies are to each other; just as the light of a taper is more intense near to it than at a distance.

A board of a foot square, at a certain distance from a light, just shadows a board of two feet square at double distance; but a board with a side of two feet has four times as much surface as a board with a side of one foot, as is seen in the *figure*,



where C represents the place of a light, AB a square board at a certain distance from it, and ED a shadowed board, of which the side is just twice as long, at double distance, and of which one fourth, as the corner, FD, is equal to the whole of the smaller square, AB. And thus light, and attraction, and indeed every influence from a central point, decreases in the same proportion, viz., it is only one-fourth as strong at double distance, or four times as strong at half distance; and in like manner for all distances.

What weighs 1,000 lbs. at the sea-shore, weighs five lbs. less at the top of a high mountain or raised in a balloon; and at the distance of the moon, its weight or force towards the earth is diminished to five ounces, as is proved by astronomical tests.

Attraction has received different names, as it is found acting under different circumstances.

Gravitation is the name given to it, when acting at a distance, as in the cases of the moon lifting the tides—the sun and earth attracting each other—a stone falling, &c.

Cohesion is the name, when acting at very short distances, as in keeping the atoms of a mass together.

At first sight it might appear that it cannot be the same cause which draws a piece of iron to the earth with the moderate force called its weight, and which keeps the constituent atoms of the iron in such strong cohesion; but when we recollect the law that attraction is stronger as the things are nearer to each other, the difficulty vanishes. Atoms in absolute contact would be a million times, nay, infinitely nearer to each other, than when only a quarter of an inch apart, and therefore if the heat among them allow them to approach near to each other, the atoms of any cohering mass must attract mutually with great force. Were it not that the surfaces of bodies are in general so very rough and irregular, that if applied to each other, they can only touch, perhaps, in four or five points out of a million which the surface contains, bodies would be invariably sticking together or cohering by accidental contact. Besides this irregularity of surface, however, there is another reason explained a little further on, which prevents such cohesion. The effect of artificially smoothing the touching surfaces is seen in the following examples:—

Similar portions being cut off with a clean knife from two leaden bullets, and the fresh surfaces being then brought into contact, with a slight turning pressure, the bullets will cohere, almost as if they had been originally cast together.

Fresh cut surfaces of India rubber or caoutchouc adhere perfectly: we are hence enabled easily to make elastic air-tight tubes, by cutting off the edges of a strip of India rubber and bringing the cut surfaces into contact round a pencil-case or such thing, and fixing them there for a time with tape or cord.

Two pieces of perfectly smooth plate glass or marble, laid upon each other, adhere with great force.

So also any other two well-polished and perfectly flat surfaces.

A flat piece of glass, balanced at the end of a weighing beam, and then allowed to come into contact with water, will be found to adhere to this, with much more force than the weight of water remaining upon it, when it is again forcibly raised. This proves the cohesion or attraction of the water particles among themselves, as well as to the glass; for otherwise the solid body could only be held down by the weight of the water which directly adhered to it.

The particles of water cohere strongly enough among themselves, for small needles gently laid on the surface to float; because the weight of these is not sufficient to overcome the cohesion of the water surface.

For the same reason many light insects can walk upon the surface of water without wetting themselves.

It is chiefly the different degrees of the attraction of cohesion in different liquids that make their drops or gutts from the lip of a phial to be of different magnitude. Sixty drops of water from a phial fill the same measure as 100 drops of laudanum from the same phial.

A liquid is a mass in which the attraction of cohesion is not so strong among the particles as the attraction of gravitation, and therefore they sink down until they come to a level, as will be fully explained in a future chapter.

Attraction is called *capillary* when it acts between solids and liquids where the solid is tubular or with empty spaces in it.

An open glass tube, partially immersed in water, will have the water within it, always standing above the level of that on the outside; and the difference of level will be greater as the tube is less, because, in small tubes, the glass all round being nearer to the raised water, attracts it more powerfully.

Between two plates of glass placed near to each other, the same rising of the water is observed; and if they are nearer at one perpendicular edge than at the other, the surface of the suspended water forms a certain curve.

In pouring water from a mug or bottle lip, the water will not fall perpendicularly at first, but will run down along the inclined outside of the vessel, chiefly in consequence of the attraction between this and the water; hence the difficulty of pouring from a vessel without a projecting lip.

A piece of sponge or a lump of sugar touching water by its lowest corner, soon becomes moistened throughout.

The wick of a lamp, lifts the oil to supply the flame, from two to three inches below it.

A mass of cotton thread hanging over the edge of a glass of water will empty it, as a syphon would. A towel will empty a basin of water in the same way.

Dry wedges of wood driven into a circular groove round a pillar of stone, and then moistened, swell so as to rive off the portion from the block. Millstones are thus cut off from the rock, in some quarries of Germany.

An immense weight or mass may be raised a little way, by tightening a dry rope fastened over it, and then wetting the rope.

At one time the small vessels of vegetables, were supposed to raise the sap from the roots, by capillary attraction, but this is known now to be an action of vegetable life.

Attraction has got the name of *chemical attraction* or *affinity*, when it unites the atoms of two or more distinct substances into one perfect compound.

There are about fifty substances in nature which appear in the present state of science, distinct from each other, and are therefore called *kinds of matter:* such are, the forty metals, sulphur, phosphorus, &c.; but whether these are really, originally and essentially different, or are all only the one, simple primordial matter, modified by circumstances as yet unknown to us, we cannot now positively determine.

Diamond and pure black carbon are the same substance, only the atoms are differently arranged; and the soft steel which the graver cuts as it would copper or silver, is exactly the same substance as after being tempered by heating and sudden cooling, it has become as hard nearly as diamond itself. Yet these differences are greater than appear between some substances, which we now account essentially distinct.

It is found however, that the atoms of different substances will not cohere and unite indifferently, as atoms of the same kind do, but that there are singular preferences and dislikes among them, if it may be so expressed; and when atoms of two kinds do combine, the resulting compound generally loses all resemblance to either of the elements.

Sulphuric acid will unite with copper and form a beautiful translucent blue salt; with iron it will form a green salt; but if a piece of iron be thrown into a solution of the copper salt, the acid of that will immediately let fall the copper, and take up or dissolve the iron. Sulphuric acid will not unite with or dissolve gold at all.

Twenty-five parts of quicksilver and four of sulphur unite and form the paint called vermilion. The twenty-five of quicksilver, with two parts of sulphur, form the black mass called Ethiop's mineral.

One hundred parts of lead and eleven of oxygen gas from the atmosphere, unite and form what is called red lead, used by painters.

Sea sand, or flint, and the salt called soda, when heated, unite together and form that most useful substance called glass.

Chemical attraction operating thus, does not in the slightest degree interfere with general attraction or gravity, for 113 grains of sulphur and 100 of iron combined and forming those beautiful cubes of pyrites, or gold-like metal, which are seen in slate, weigh exactly 213 grains; and as much in combination therefore, as they did when weighed separately; and thus of all other things.

The history and classification of all these facts, connected with the combinations and analysis of different substances, constitute the science of chemistry—so amusing and so useful. This science explains how the fifty kinds of matter which we have mentioned, by combining variously, form an endless diversity of substances, which constitute the mass of our globe. The causes of these various chemical modifications of attraction, are yet much hidden from us.

It is a remarkable thing that when different substances combine in the way now described, the proportions of the ingredients are always uniform, and such as seem to prove that for every atom of one substance there is one or two or three of the other. Thus, if there be ten atoms of one substance, there must be exactly ten of the other, or twenty or thirty; but there is never an intermediate number, as 13 or 23 to 10, for then an atom of the compound would consist of one atom of the first, and of one and three-tenths, or two and three-tenths, &c. of the second substance, which is absurd, as the atom is indivisible. For instance, a certain number of atoms of quicksilver, which weigh twenty-five grains, combine with a certain number of atoms of sulphur, weighing two grains, and form a black compound called Ethiop's mineral, or black sulphuret of mercury; and if a little more of either ingredient be added, it lies as a foreign mixture in the sulphuret of mercury; but if just as many more atoms of sulphur be added as at first, so that there may be double proportion to each atom of the mercury, a perfect combination of all will take place, and the substance will appear which we call vermilion. Many elementary substances will only unite in one of these proportions, so that any two such only form one compound: but others unite in several proportions, and two or more distinct compounds arise out of the same two elements.

It thus appears, that although we do not know the exact number of atoms in a given quantity of any substance; whether, for instance, a grain of sulphuret of mercury has more or less than a million of them; still we know that in that grain there are just as many atoms of sulphur as of mercury—and as the weight of the whole sulphur to that of the whole mercury is as two to twenty-five, we know that the single atoms must have the same relation.

Tables have been formed shewing the comparative weights of the atoms of different substances, and the number standing opposite to each substance is called its equivalent number—that is to say, the weight of its atom compared with the weight of the standard atom. And the equivalent of a compound substance, must be the sum of the equivalents of the ingredients, because a compound atom contains an atom of each of the ingredients.

Besides the simple cases of attraction now mentioned, there are two curious modifications called electrical and magnetical attractions, which, from their peculiarities, are reserved for consideration in a future division of this work.

"*Various Form and Magnitude*" (*see the analysis*).

The form and magnitude of bodies are often of greater importance to man than the particular nature of the substances themselves; as for instance, the form and magnitude of a column, than whether it be made of marble, or porphyry, or granite. Hence the necessity to man of being able to compare magnitudes and quantities, and therefore, of having ready standards of comparison, or *measures* of all kinds. The simplest have been chosen.

As regards *number*, he counts by the fingers of the hand, that is, by fives and tens. Common arithmetic is merely saying how many tens any quantity contains—100 is 10 tens, 1,000 is 100 tens, and so on. Eights or twelves would have answered as well for many purposes, and better for some, but as the ten fingers were the readiest objects of reference, ten is the standard now generally established.

As regards *length*, the foot (of a full-sized man) has been the common standard. Of old, the cubit or forearm—the fathom—the pace, were also much used, and the repeated applications of such measures, numbered by the fingers, or by tens, as already stated, answered to measure any length or distance.

As regards *surfaces*, the standards used have been the simplest conceivable forms,—the circle, square, triangle, &c.

And in *solid* magnitudes, corresponding forms have served—the globe or sphere, the cube or solid with square sides, the pyramid and cone.

The parts of the human body mentioned above as used for measures of length, vary of course with the size of the individual, and are not therefore fixed and general standards; and if the human race undergo any change of stature in the course of ages, as some have supposed, the records of measurements, preserved in remote history, must be inaccurate for the present times. Now as the measure of length becomes really the universal measure; because surfaces are measured by the length of their sides, and solids by that of their diameters, and weights by the tendency downward of a certain sized solid; the accuracy of modern science has sought some fixed and natural standard, belonging equally to all times and countries and races of men. Recently, two such have been fixed upon. The one is the length of a pendulum that beats seconds under known circumstances. The other is the circumference of our globe itself. The size of the earth has now been accurately ascertained, by careful measurements of known segments of it in various situations, and the French nation have adopted the 40 millionth part of the circumference (nearly the English yard), as their general standard; and upon it, as a basis, have erected the most perfect decimal system of measures which the world has yet seen. This system is, of course, as natural to all other countries as to France, and may probably at last become common to all, and with infinite advantage to all.

The whole science of numbers, in its highest flights, is merely comparison of the various standards, described above, with each other; or of other forms and quantities with these. And the standards are now so familiar to all men living in civilized society, from types or examples being constantly under view, that almost every person arrived at years of discretion knows them well, and is therefore really acquainted with many of the fundamental truths of mathematics; and such persons are daily acting in obedience to these truths as their guides, without thinking that they are practical *mathematicians*, like the illiterate gentleman in the comedy, who had been speaking *prose* all his days, without suspecting that he was capable of doing any thing so learned.

It is remarkable how much the really simple and attractive science of comparing quantities, in other words, the *science of measures*, or *mathematics*, has been rendered terrible to the great mass of mankind, by the mystery with which it was surrounded in early times, and which still, under the barbarous names, borrowed from all languages, of *arithmetic*, *algebra*, *fluxions*, *geometry*, *mathematics*, &c. deters common minds from the study. These names have long sufficed to conceal the beautiful simplicity and uses of the science, which lie under them; but men of talent are now employed in smoothing the avenues to these treasures, by translating the old technicalities of the science into the common languages, and will thus, probably, soon open the most useful parts, to the easy reach of common understandings and of common leisure. By the same means dormant genius may be aroused, in all classes of society, to join in the general work of scientific advancement.

It is a common saying, that natural philosophy is altogether founded on mathematics, or the science of number—and it is a perfectly true saying; but a faulty understanding of this truth has needlessly excluded the great mass of mankind from the enjoyment and advantages which the study of natural philosophy is calculated to afford. It has hence not been suspected that the mathematics of common sense and observation, as described above, and which all men possess, is perfectly sufficient for understanding the great laws of nature, provided they are explained in common, and not in technical language. Yet, so much of unity, simplicity, and harmony, are there in this universe which surrounds us, that even the simplest properties of the few standard quantities and forms mentioned above, are those which give exact cognizance of the most important circumstances in the phenomena and states of nature.

The sublime law of attraction or gravity, the discovery of which alone would have immortalized our Newton, was easily illustrated at page 13, by reference to a succession of boards, which exactly shadow each other, when placed in a row from a candle.

Although the degree of acquaintance with the *science of measures*, which is general among civilized men, is thus sufficient to enable them to comprehend the great laws of nature, yet the man who has practically to apply his knowledge to particular cases, must generally be ready with his arithmetic, and other technical aids; as, for in-

[illegible] to determine the [illegible] [illegible] for an arch, or to ascertain the [illegible] of a [illegible] [illegible].

And now, [illegible] [illegible] [illegible] [illegible] multiplied so much, the truth may be told, that a man's education is very imperfect, if the science of nature has been neglected. [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] is in general as charmed by the [illegible] of the [illegible], and by the [illegible] of the [illegible] [illegible] of [illegible], which can [illegible] [illegible] [illegible] through such [illegible] as [illegible] themselves, that it [illegible] no other [illegible] to [illegible] [illegible].

* [illegible] more or less close, according to the quantity of heat among them; hence solid, fluid, air, &c.—read the Analysis, page 1.

Were there only atoms and attraction, as now explained, the whole materials of creation would rush into close contact, and the universe would be one huge solid mass of stillness and death. There is heat or caloric, however, which directly counteracts attraction, and singularly modifies the results. It has been described by some, as a most subtile fluid, pervading all things, as water does a sponge; others have accounted it merely a vibration among the atoms. The truth is, that we know little more of heat as a cause of repulsion, than of gravity as a cause of attraction: but we can study and classify the phenomena of both most accurately.

When a continued addition of heat is made to any body, it gradually increases the distance of the constituent atoms, from each other; first, dilating the body; secondly, softening it if solid, and melting or fusing it, that is reducing it to the state of liquid, by overcoming the attraction of cohesion; thirdly, repelling the atoms to still greater distances than in liquids, and converting the substance into elastic fluid or air. Abstraction of heat causes return of states in the reverse order.

Ice heated becomes water, and water heated becomes steam, and steam cooled becomes water again, and water cooled becomes ice. Ice, water and steam, therefore, are the three forms or states of one of the most common substances in nature, the material of the ocean.

Other substances are similarly affected by heat, but as all have different relations to it, some requiring much for liquefaction, and some less, we have that beautiful variety of solids, liquids, and airs, which makes up our external nature.

Dilatation.—A rod of iron, which, when cold, will pass through a certain opening, and will lie lengthwise between two certain points, when heated becomes too thick and too long to do either.

For accurate measurement, therefore, the rods or chains used as the measure, must always be at the same temperature, or due allowance must be made for the difference.

The wall of a building had begun to bulge out, so as to threaten its stability. No force tried could return it to perpendicularity, until the idea occurred of connecting it with the opposite wall by bars of iron: these were then heated alternately by lamps placed under them, and while lengthened in consequence, nuts were screwed tight at their extremities; so that on again cooling and contracting, they pulled the wall back to its place.

The iron rim of a coach-wheel, when heated, goes on loosely and easily, and when afterwards cooled, it binds the wheel most tightly, giving incredible firmness and strength.

Hoops on masts and on casks act in the same way.

The common thermometer for measuring degrees of heat, is a glass bulb filled with mercury or other fluid, and having a narrow tube rising from it. As the fluid is heated it expands, and rises in the tube, marking the degree.

A flaccid bladder of cold air when heated appears full and will even burst.

" *Liquid and Air.*"

A piece of gold, lead, pitch, ice, sulphur, or of other thing, if heated, melts or becomes liquid; each substance requiring however a different degree of heat—gold requires 5000 degrees, lead 600, ice 32, and so forth; and if the heating be afterwards continued, most things at particular temperatures suddenly expand again to many times the liquid volume, and are then called aeriform fluids.

The conversion of water into steam is familiarly known to all. One pint of water driven off as steam from the boiler of a steam engine, fills a space of nearly 2000 pints, and raises the piston through this, with a force of many thousands of pounds: it immediately after appears again in the cold condenser as a pint of water.

Six times as much heat is required to convert a pint of water into steam, as to raise it from cold to boiling temperature; but as the steam occupies nearly 2000 times the space of the water, this proves that heat merely produces a repulsion among the particles, and by no means fills up the interstices. The steam confined above boiling water, does not appear hotter to the thermometer than the water itself: its excess of heat therefore received the name of latent heat from Dr. Black, whose genius shed such a useful light on this part of knowledge.

The latent heat of common air is made sensible in the *match syringe*. In this, the piston is driven down quickly and strongly, so as to compress very much, the air which is underneath it, and the heat then squeezed out of that air, or condensed with it, is sufficient to light a match attached to the bottom of the piston.

Not only are spirits, æthers, oils, &c. convertible into steam or vapour, as water is; but sulphur, phosphorus, mercury, and indeed all the metals and elementary substances;—some of them require, however, most intense heats.

The varieties of form, then, in the bodies on the face of this earth, are merely accidental; as depending on the temperature of the earth, and have nothing to do with the permanent nature of the things.

In the planet Mercury, which is near the sun, resin, tallow, wax, and many vegetable substances deemed by us naturally solid, would all be liquid, as oil is with us; and a mixture of tin, zinc, and lead, which with us is solid metal, would there be liquid like our quicksilver. Our water, oils, and spirits, would there all be in the state of steam or air, and could not be known as liquids at all, except by cooling processes and compression, such as we have lately learned to use for reducing our different airs to the form of liquids.

In the cold planet Herschell again, which is nineteen times farther from the sun than our earth, water can only be known as a rock crystal, which fire would have to melt as it does glass with us: our oils would be as butters or resins, and quicksilver might be hammered, as lead or silver is with us.

On our own earth, near the equator, common sealing-wax will not retain impressions; butter is oil in the day, and a soft solid at night; and tallow candles cannot be used.

Near the pole, in winter, the quicksilver from a broken thermometer is a solid mass of metal; water must be melted by fire for use: oils are solid, &c.

To judge then of the constitution of nature aright, we must always take extended surveys, and not allow prejudice to mislead us, as was the case with the Indian potentate, who put a traveller to death for saying that he had been in a remote northern country, where water was sometimes to be seen solid like crystal, and sometimes white and fleecy, like feathers.

The ancients believed that there were just four elements concerned in forming our globe and all upon it: viz. *earth*, *water*, *air*, and *fire*. What a contrast between former and present knowledge!

Repulsion without sensible Heat.

As we stated in a former paragraph, that besides general attraction, under the names of gravity, cohesion, and capillary attraction, there are modifications under the names of electrical and magnetic attractions; so we have now to remark, that, besides the general repulsion of heat just described, there are peculiarities which we call electrical and magnetical repulsions. Whether these depend on different causes altogether, or are only modifications of effect from the same cause, we cannot yet positively decide.

It is a curious fact connected with the subject, that there seems to be a film of repulsion, so to express it, covering the general surfaces of all bodies, and preventing their meeting in absolute contact, even when they appear to the human eye to do so. Were it not for this, things would be constantly coming so close to each other that they would stick or cohere, disturbing all the common operations of nature and art. A few particular cases in which cohesion may be easily effected, were enumerated at page 15. The following facts illustrate this superficial repulsion, and the means which art uses to overcome it to answer particular ends.

Newton found, that a ball of glass, or a watch-glass, laid upon a flat surface of glass, does not really touch it, and cannot be made to do so by a force even of 1000 pounds to the inch.

For the same reason it is, that if we break glass, or stone, or porcelain, or indeed almost anything, we cannot make the parts cohere again by simply pushing them together as they were before; and where a union between separate masses is desired, we are compelled to have recourse to various artifices.

Gold leaf laid upon clean steel, and then forcibly struck upon it by a hammer, coheres to it and gilds it permanently.

But iron cannot be made to cohere to iron, except by making both pieces red hot before hammering. This process is called welding.

Iron and platinum are the only metals that can be welded.

Tin and lead, in sheets, pressed together between the strong rollers of a flatting mill, cohere.

The other metals require to be melted together before the superficial repulsion gives way to allow the parts or quantities to cohere or run into one mass. It is thus, for instance, that gold, silver, lead, &c. are treated.

In many cases the kind of matter cannot thus be melted, (as wood or marble,) and then it is common to use some sort of glue or cement. Such cements must have strong attraction for both substances, and must be tenacious in themselves, when dry or cool; solder, paste, mortar, glue, &c. are the chief matters of this sort.

" *Certain modifications of Attraction produce the subordinate states, called crystal, porous, dense, &c.*" (*read the analysis, page* 5.)

It is a remarkable circumstance, that attraction, in causing the atoms to cohere so as to form solid masses, seems not to act equally all around each atom, but between certain sides or parts of one, and corresponding parts of the adjoining ones; so that when they are allowed to cohere according to their natural tendencies, they always assume a certain regular arrangement and form, which we call crystal. Because in this circumstance they seem to resemble magnets, which attract each other only by their related poles; the fact has been called the polarity of atoms. It is the cause of several of the other peculiarities above enumerated, as elasticity, &c.

Crystallization is exemplified in the following particulars:—

Water beginning to freeze, shoots delicate needles across the surface; these thicken and interweave until the whole mass has become solid: but the crystalline arrangement always remains, and in most substances is remarkably shewn when the mass has been broken, by the forms of the surfaces left.

Moisture freezing on the cold window-pane in winter, exhibits the most beautiful variety of arborescence.

A flake of snow, viewed in the microscope, is seen to be as symmetrically formed as a fern leaf or a swan's feather.

If a bit of copper be thrown into a solution of silver in nitric acid, the copper is preferred by the acid to the silver, and is dissolved accordingly; and the silver, during its precipitation or separation, assumes the form of a beautiful shrub or tree, resting on the remaining copper as its root. This appearance is called the *arbor Dianæ*.

Any metal which has been melted, when allowed to cool again, slowly and at rest, becomes solid on the outside of the mass first. If before the cooling be completed, the remaining liquid be poured from within, a curious internal crystalline structure, like grotto work, is seen. What is called the grain of a metal is the result of this crystallization.

Saltpetre, glauber salt, copperas (to use popular names), or any other of the many neutral salts, being dissolved in water, and the water being then allowed slowly to evaporate, re-appears in beautiful regular crystals, each salt having its peculiar forms.

All the precious stones are crystals, and can only be well cut parallel to their natural faces.

The basaltic pillars of the Giant's Causeway in Ireland, and of the Isle of Staffa, which appears like a garden supported on magnificent columns in the midst of the ocean, are natural crystalline arrangements of particles, equalling in regularity and beauty any human work, and so far surpassing in grandeur even the Egyptian pyramids, that superstitious conjecture naturally supposed giant architects.

Much ingenuity has been employed to account for the exact forms which different bodies assume; but the subject is not yet reduced to a state fitting it to be a part of this elementary study. A familiarity with the various figures, which the exact science of measures treats of, is required in the person who expects to pursue it with pleasure or advantage. The facts are extremely curious, and the scientific investigation of them may ultimately give very important information as to the intimate constitution of material nature.

It would be endless to go on enumerating crystalline masses, for all nature's forms are regular and symmetrical, in the inanimate creation, as well as in vegetables; and what we see of broken continents, and islands, and rocks, and wild alpine scenery, are the effects of subsequent convulsions, which have deranged primitive and natural order.

Porous.—This crossing of the constituent crystalline needles or plates in bodies, causes them to be porous or full of small vacant spaces. These are often visible to the eye, more frequently so to the microscope, but are always to be proved in some way.

Owing to the porosity or new arrangement of atoms on solidifying, water and a very few other things become more bulky in the change from the liquid to the solid state, notwithstanding the nearer approach of the cohering particles. Water does this with such force, as to burst the strongest vessels which art can provide, and in winter to split rocks, where it has been admitted into crevices. It is this agency of freezing water, which is gradually breaking down the alpine summits, and continually discharging the destructive fragments into the vallies.

The stone called hydrophane (agate) is opaque, until dipped into water, when it absorbs one-sixth of its weight into its pores, and then gives passage to light.

In crystallized sugar, and in many stones, much water enters without increasing the size.

A kind of sand-stone, made of vessel-shape, is used as an excellent filter or strainer for water.

Pressure forces water through the pores of the most solid gold; as was seen in the famous Florentine experiment, where a hollow, thick, golden ball, was filled with water, and squeezed, to try the compressibility of water, until it perspired all over.

But the examples of porosity in vegetable and animal bodies are the most remarkable.

Bone is a tissue of cells and partitions, as little solid as a heap of empty packing boxes.

Wood is a congeries of parallel tubes, like bundles of organ pipes. It has lately been proposed to prepare wood for some purposes, as for making the great wooden pins or nails used in ship-building, by squeezing it to half its bulk between very strong rollers. It thus becomes nearly as heavy and as strong as metal.

A piece of wood sunk to great depth in the ocean, and exposed to the pressure there, has its pores filled with water, and becomes as heavy as stone. Thus the boat of a whale-fishing ship, which had been dragged far under water by a whale, on being afterwards drawn up, was supposed to be bringing a piece of rock with it.

A piece of cork in a strong close glass vessel, nearly full of water, will float at the top; but if more water be forcibly pumped into the vessel, the cork will thereby be squeezed and reduced in size, until it becomes heavier than water, and sinks. On allowing water to escape, it will resume its bulk and rise. A cork sunk 200 feet under water will never rise again of itself.

A bottle of air, corked and let down thirty or forty feet into water, often comes up again full of water, and with the cork still in its place; the explanation being, that the cork, when far down, was so squeezed as to become small enough to allow the water to pass in by its sides, and on rising again it regained its former size.

"*Density*," or the quantity of atoms which exist in a given space, varies much in different substances.

A cubic inch of lead is forty times heavier than the same bulk of cork. Mercury is fourteen times heavier than an equal bulk of water.

The density depends on three circumstances: first, on the degree of porosity just now explained; secondly, on the size or weight of the individual atoms; thirdly and chiefly, on the proximity of the atoms in the solid or interstitial parts, where they are the most closely connected; for, from many circumstances it appears, that the atoms even of the most solid bodies are not in actual contact, but are retained in their places by a balance between attraction and repulsion—thus,

A body dilates or contracts, according as heat is added to or taken away from it.

A weight placed on an upright rod of iron, &c. shortens it, and if suspended to it, lengthens it,—the rod in both cases returning to its former length when the weight is removed.

When a plank or rod is bent, the atoms on the concave side are approximated for the time, and on the convex side they are drawn more apart.

Tin and copper melted together to form bronze, occupy less space by one-fifteenth than they did when separate: proving that the atoms of one are received partially or wholly into what were vacant spaces in the other.

And so of many other mixtures.

A pound of water and a pound of salt, when mixed, form two pounds of brine, but they then measure in bulk much less than when separate. So also a pound of sugar dissolved in a pound of water.

Water and liquids generally resist compression very much, but they yield enough to shew that the particles are not in contact. It is found that 1,000 fathoms down in the sea, the superincumbent weight of water compresses that below it, into bulk one hundredth less.

In aeriform bodies the atoms are very distant, and easily compressed, for a pint of water converted into the aeriform state (steam), acquires 1,800 times its former bulk or more; and a hundred pints of air may be compressed into a pint vessel, as in the chamber of an air-gun; and if the pressure be still increased, the atoms of air at last collapse and form an oily liquid. The heat which was contained in this air, and gave it its form, is squeezed out in this operation, and becomes sensible in every thing around.

From these proofs of the non-contact of the atoms, even in the most solid parts of bodies, from the very great space obviously occupied by pores, as if the mass were not more solid than a heap of empty boxes, of which the apparently solid parts were still as porous in a second degree, and so on: and from the great readiness with which light passes in all directions through very solid bodies, as glass, rock crystal, diamond, &c. it has been argued that there is so exceedingly little of really solid matter in any mass, how dense soever it may appear, that the whole world might be compressed into a nutshell, if the atoms could be brought into absolute contact. We have as yet no means of speaking positively on this subject.

Equal bulks of different bodies being weighed, the comparative weights so found are called their *specific gravities;* and they depend on the circumstances now explained as regulating the density.

In comparing them, it was necessary to choose a standard; and water, as being the most easily procurable at all times and in all places, has been generally adopted. The following are a few examples.

The metal called platinum, the heaviest of known substances, is about twenty-two times as heavy as an equal bulk of water—gold is nineteen times as heavy—mercury thirteen and a half—lead eleven—iron eight and a half—copper eight—

common stones about two and a half—woods from a half to one and a half—cork one quarter, &c.

" *Hardness*" is not proportioned, as might be supposed, to the density of the different bodies, but to the polarity of the atoms in them, or the force with which the atoms hold their places in some particular arrangement.

Soft gold is four times heavier than the hard diamond; and in mercury, where, as a fluid, the particles yield to the least pressure, there is nearly twice the density of the hardest steel. Hardness is measured generally by the circumstance of one body being capable of scratching another. It is worthy of notice, however, that the powder or dust of a softer body will often aid in wearing down or polishing one that is harder.

Diamond is the hardest of known substances. It cuts or scratches every thing else, and is generally polished by means of its own dust.

Glass-cutters use a point of diamond as a glass-knife, for dividing and shaping their panes.

Common flint also cuts glass, as is seen in the writings made by it on window panes.

It is remarkable, that the preparation of iron called steel, which is originally soft like pure iron, on being heated and suddenly cooled, in the process called tempering, becomes nearly as hard as diamond. The discovery of this fact is perhaps second in importance to none which man has made: for it has given him all the edge tools and cutting instruments by which he now moulds every other substance to his wishes. A savage will work for twelve months, with fire and sharp stones, to cut down a great tree and to give it the shape of a canoe; while a modern carpenter, with fit tools, could accomplish the same object in a day or two.

The valuable idea has lately been realized of making engravings on plates of soft steel instead of copper, and of afterwards tempering the steel to such hardness that it may be used as a type or die to make its impression, not on paper, but on other plates of soft steel, or of copper; each of which is then equal in value to an original and distinct engraving. By this means the beautiful productions of art, instead of being limited to a comparatively small number of copies and persons, may be multiplied almost to infinity, and may thus become the cheap delight of all.

"*Elasticity*" is present in a mass when the atoms, cohering in a particular arrangement only, yield, however, to a certain extent when force is applied, but immediately move back again or regain their natural positions on the disturbing force being withdrawn.

Elastic bodies vary much in the extent to which they yield without breaking, and in the degrees of perfection with which, after the bending or displacement of atoms, they return to the former state. India rubber is very elastic, for it yields far; but it is not perfectly elastic, for when stretched much or often, it soon becomes permanently elongated. Glass, again, is perfectly elastic, for it will retain no permanent bend; but, unless in very thin plates indeed, it will not bend far without breaking.

All hard bodies are elastic, as steel, glass, ivory, &c.; and many soft ones, as caoutchouc, silk thread, a harp-string, &c. The aeriform bodies are all perfectly elastic, as rudely seen in a bladder filled with air, and they will change volume to a very great extent. Liquids are so too, but to a small extent.

A good steel sword may be bent until its ends meet, and yet, when allowed, it will return to perfect straightness.

A rod of bad steel, or of other metal, will break in bending, or will retain a bend.

An ivory ball, let fall on a marble slab, rebounds by its perfect elasticity nearly to the height from which it fell, and no mark is left on either. If the slab be wet, it is seen that the ivory had been a good deal flattened at the point of contact, for a considerable circular surface of the slab is found dried by the blow. Billiard balls scarcely lose their polish by long wear, although the touching parts yield at every stroke.

A marble chimney-piece long supported by its ends, is found at last to be bent downwards in the middle, and the bend is permanent.

A steel watch-spring, although so often and so much bent, resumes its original form when freed at the end of a century; but occasionally, without evident cause, while yet in action, it will suddenly break.

Elasticity is a property of bodies of great utility to man, as in his time-pieces, carriage-springs, gun-locks, &c. &c.

" *Brittleness*" designates that constitution of a body where, with hardness, and elasticity which is perfect as far as it goes, the cohesion among the atoms is such, that a very slight change of position among them is sufficient to produce a rupture. Therefore, when the force necessary to produce that little change is applied, the cohesion gives way altogether. It belongs to most very hard bodies.

Glass scratches an iron hammer, which proves that it is harder than iron—yet glass is the very type of fragility; a bit of soft wood breaks it, or indeed a blow from any thing.

Steel, when tempered so as to be very hard, becomes brittle also. The steel chisels and tools with which artificers now cut and shape the metals, as they formerly did wood, require of course to be exceedingly hard; but they thus lose of their toughness, and hence are frequently broken. Cast iron, which is much harder than malleable or wrought iron, is very brittle, while soft iron and steel are the toughest things in nature.

" *Malleable*," or reducible into thin plates or leaves by hammering. This property, in opposition to elasticity and brittleness, belongs to bodies whose atoms cohere equally in whatever relative situations they happen to be, and which therefore yield to force, and shift about among each other, almost like the atoms of a fluid, without fracture or change of property.

Gold is remarkably malleable, for it may be reduced to leaves of the thinness of 282,000 to the inch. For gold-beaters the metal is first formed into rods, these are afterwards rolled or flattened into ribands, the riband is cut into portions, which are extended by hammering to great breadth and thinness, and being again divided into portions, they are hammered and extended to the thinness described.

Silver, copper, and tin may also be hammered very thin. Most other metals tear and break before the operation is carried far; and some, on being struck, break at once like glass.

" *Pliant,*" as a character of body, agrees with malleable, in the cohesion not being destroyed by change of direction among the atoms, but the same atoms always remain in contact in pliant things. They are chiefly animal and vegetable fibres, and membraneous structures—silk, bladder, lint, hemp, &c. &c.

" *Ductile,*" or susceptible of being drawn into wire. One would almost expect malleability and ductility to belong to the same substances and in the same degrees—but it is not so. In ductile substances, as in malleable, the atoms seem to have no more fixed relation of position among each other than in a liquid, and yet they cohere very strongly.

One end of a rod, of iron, or of gold, or silver, or copper, being reduced so as to enter an opening in a plate of steel, and the rod being of a certain temperature, the point is seized by strong nippers on the other side of the plate, and the whole rod is drawn through. It is reduced, of course, to the size of the opening, and lengthened in a like proportion. The operation being repeated through smaller holes successively, a wire may at last be obtained of the size of a hair.

Dr. Wollaston's ingenuity produced platinum wire smaller than spider's thread. He drilled a hole in the axis of silver wire, and filled it with small platinum wire. He then drew the compound piece into the smallest wire possible, and on dissolving the silver from the outside, a beautiful filament of platinum remained, finer than any known substance.

The order in which metals may be ranged according to their ductility is, platinum, silver, iron, copper, gold, &c.

Melted glass has great ductility. The workers draw or spin it into threads, by merely attaching a point, pulled out from the mass, to the circumference of a turning-wheel. A uniform thread continues to be drawn out and wound upon the wheel, at the rate of 1,000 yards or more per hour. This glass thread is cut into bunches, resembling bunches of beautiful white hair.

" *Tenacity*" means the force of cohesion among the atoms of any mass, whatever the nature of the mass in other respects; and it belongs more or less to all substances, not excepting even liquids.

This property varies much in different substances. Iron and its modification called steel have it in the most remarkable degree.

The following table shews the comparative tenacity, or strength to bear pulling, of different metals and woods. Supposing similar wires or rods of each to be used, and of such size that the surface of a cross section would be one-thousandth of a square inch, the weights supported would be nearly as follows:—

METALS.

Cast Steel, 134 lbs., equal to about 39,000 feet of the wire.

Best wrought Iron,	70 lbs.
Cast Iron	19
Copper	19
Platinum	16
Silver	11
Gold	9
Tin	5
Lead	2

WOODS.

Teak	13
Oak	12
Beech	12½
Ash	14
Deal	11

Iron, therefore, compared in this way, is five or six times stronger than oak.

Certain animal substances have great tenacity.

The silk-worm's thread, which gives men their strongest connecting or sewing material, and which has such flexibility united with its strength.

The ligaments and tendons of the animal body, exhibiting at once such admirable strength, elasticity, and suppleness! These, when dried, and otherwise prepared, formed the bow-strings of our remote forefathers.

The hair or wool of animals, twisted into threads, and woven into the strong and beautiful textures of the loom.

Strips of animal intestine, prepared and twisted, forming the cords of harp and violin—in strength and uniformity rivalling the steel wires of keyed instruments.

Man's gradual discovery of substances possessed of great tenacity, and which he could yet easily mould and apply to his purposes, has been of unspeakable importance to his progress from the state of barbarism to high civilization! The place of the hempen cordage of European navies is still held in China, by twisted canes and strips of bamboo; and even the hempen cable of Europe, so great an improvement on former usage, is now rapidly giving way to the more complete and commodious security of the iron chain.—And what a magnificent spectacle is it, at the present day, to behold chains of tenacious iron stretched high across a channel of the ocean, as at the Menai Strait between Anglesea and England, and supporting an admirable bridge-road of safety, along which crowded processions may pour, regardless of the deep below, or of the storm; while beneath, ships with sails full-spread, may pursue their course, unmolesting and unmolested!

SECTION II.—THE FUNDAMENTAL TRUTHS EXPLAINING THE MOTIONS OR PHENOMENA OF THE UNIVERSE.

ANALYSIS OF THE SECTION.*

The bodies or masses composing the universe may be at rest or in motion, and there is an inertia *or stubbornness in their component matter, which resists all change, and renders force equally necessary to produce motion, to take it away, or to bend it. Uniform straight motion is, therefore, as naturally eternal as rest. The quantity of motion in a body, measured by its velocity and quantity of matter, is hence also the measure of the degree and direction of the force or forces which produced it, and of the force or momentum which the body can exhibit again when opposed or made to act itself as a cause.*

The two great forces of nature, attraction *and* repulsion, *acting upon* inert matter, *produce the* equable, accelerated, retarded, *and* bent *motions which constitute the great phenomena of the universe.—Tides, currents, winds, falling bodies, &c. obey* attraction.—*Explosions, steam, collision, &c. obey* repulsion. *And as in every case of attraction or repulsion, two masses at least must be concerned, there can be no motion or* action *in the universe, without a concomitant and opposite motion or* reaction.

" *Motion,*"

Were there no motion in the universe it would be dead. It would be without the rising or setting sun, or river-flow, or moving winds, or sound, or light, or life.—To understand the general nature and laws of the motions or changes which are going on around him, is to man of the greatest importance, as it enables him to adapt his actions to what is coming in futurity, and often to interfere so as to control and direct futurity, for his special purposes.

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* The reader should here re-peruse the title of the chapter at page 5, and the analysis of Section I.

Motion is the term applied to the changing of place among bodies, and is described in any particular case, by referring to fixed objects and standards.

A man sitting on the deck of a sailing ship has *common* motion with the ship: if walking on the deck, he has *relative* motion to the ship: but if he be walking towards the stern, just as fast as the ship advances, he is at rest relatively to the bottom or shore. A ship sailing against the tide, just as fast as the tide runs, has motion relatively to the water, but rest relatively to the earth. *Absolute* motion is that which is relative to the whole universe, or to the space in which it exists. We have no means of ascertaining such: for although we know how fast our globe whirls upon its axis and round the sun, we have no measure of the motion of the sun himself—revolving probably round some more distant centre, and carrying all the planets with him.

Motion is called *rapid*, as that of lightning—*slow*, as that of the sun-dial shadow: both terms having reference to ordinary intermediate velocities. It is called *straight*, or *rectilineal*, in the observed path of a falling body—*bent*, or *curvilinear*, in the track of a bullet, shot obliquely—*accelerated*, when a stone is falling to the earth—*retarded*, while the stone thrown upwards is rising to the point where it stops, and from whence it again descends.

"*The inertia or stubbornness of bodies, resisting change of state, whether they be in motion or at rest.*"

That bodies tend to continue in the state of motion or of rest in which they happen to be, so as to render force necessary to change the state, is seen in the following facts. The scientific term used to express the general truth is *inertia*, and sometimes the words *obstinacy* and *stubbornness* have been substituted as farther explanatory.

When the sails of a ship are first spread to receive the force or impulse of the wind, the vessel does not acquire her velocity at once, but slowly, as the continuing force gradually overcomes the inertia of her mass. If the sails are afterwards suddenly taken in, she does not lose her motion at once, but slowly again, as the continued resisting force of the water destroys it.

Horses must make a greater effort at first to put a carriage into motion, than to maintain the motion afterwards. And a strong effort is required to stop a moving carriage.

When a carriage hanging from springs first begins to move, the body of it appears to fall back, and a person within, seems to be suddenly thrown against the cushion behind. When the carriage stops again, the body swings forward, and if it be very suddenly a careless passenger may find his head pressing through a front glass. These particulars prove the inertia, first of rest, and secondly of motion.

A man standing carelessly at the stern of a boat, falls into the water behind, when the boat begins to move; because his feet are pulled forward, while the inertia of the body keeps it where it was, and therefore without its support. The stopping of a boat again, illustrates the opposite inertia of motion, by the man's falling forward.

A bad rider on horseback may be left behind, when his horse darts off suddenly, or may be thrown off on one side by the horse starting to the other. A horse at speed, stopping suddenly, often sends his cavalier over his ears.

A young gentleman, unpractised in driving, ran his curricle against a heavy carriage on the road, but foolishly and dishonestly excused his awkwardness, in a way which led to his father's prosecuting the coachman for furious driving. The youth and his servant both swore, that the shock of the carriage threw them over their horses' heads, and thus they lost their cause by unwittingly proving, that the faulty velocity was their own.

A man jumping from a carriage at speed, is in great danger of falling; for he reaches the ground with as much forward velocity, as a man has who is running with the speed of the carriage; and unless he advance his feet as in running, to support his advancing body, this must as certainly be dashed to the ground, as is the body of a runner who trips, or whose feet are suddenly arrested. A racer who receives the signal to stop, and a man jumping from a flying vehicle, must check their motion in exactly the same way.

A person wishing to leap over a ditch or chasm, makes a run first, that the motion thereby acquired may help him over. A standing leap falls much short of a running one.

An African traveller saw himself followed by a tiger, from which he could not escape; but perceiving that the animal was watching an opportunity to seize him, by a spring or leap, he artfully led it to where the plain terminated in a precipice hidden by brush-wood, and he had just time to transfer his hat and cloak to a bush, and to retreat a few paces, when the tiger sprung upon the bush, and by the motal inertia of his body, was carried over the precipice, and destroyed.

From a glass of water suddenly pushed forward on a table, the water is spilt or left behind, but if a glass full of water be in motion, as when carried by a person walking, and be then suddenly stopped, as by coming against any thing fixed, the water is thrown or spilt forward.

A servant carrying a tray of glasses or china in the dark, and coming suddenly against an obstacle, hears all his freight slipping forward, and crashing at his feet: and a too hurried departure with such a load would cause equal destruction, on the other side.

If a guinea be laid on a card, and this on the point of the finger, a smart fillip or blow to the edge of the card will cause it to dart of, but the guinea, by it's inertia, will remain resting on the finger.

When we desire a person, with suspected disease of the brain, to shake his head, and tell whether and where he feels pain, we are doing nearly as if we touched the naked brain with the finger to find the tender part; for the inertia of the brain, when the skull is moved, causes a momentary pressure between it and the skull, almost equivalent for our purpose to such a touch.

This kind of pressure is sufficient to break and destroy tender wares, in packages which are too suddenly moved or stopped.

A weight suspended by a spring on ship-board is seen vibrating up and down as the ship pitches with the waves. It seems to fall as the ship rises, and *vice versâ:* but the motion is really in the ship, and the rest is in the weight. A heavy weight so supported, and connected with a pump-rod, would work the pump.

Like the weight last mentioned, the mercury of a common barometer on ship-board is seen rising and falling in the tube, and until the important improvement was lately made, of narrowing the tube in one place to prevent this, the barometer was useless at sea. The explanation is, that the tube rises and falls with the ship, from being connected with it, but the mercury, which plays freely in the tube, and is supported by the atmosphere, tends, by its inertia, to remain at rest, and makes the motion of the ship apparent. It seems to fall when the ship rises, and to rise when the ship falls.

Like the mercury in the barometer tube on ship-board, the blood in the vessels of animals is similarly affected under similar circumstances. In a long vein below the heart, when the body falls, the blood, by its inertia and the supporting action of the vessels, does not fall so fast, and therefore really rises in the vein; and as there are valves in the veins preventing return, the circulation is thus quickened without any muscular exhaustion on the part of the individual. This explains the effect of the movement of carriages, vessels at sea, swings, and of passive exercise generally, on the circulation, and leaves it no longer a mystery why these are often so singularly useful in many states of weak health.

If a cannon ball were to break to pieces in its flight, its parts would still advance with the previous velocity. Thus, in the deadly contrivance of the shrapnell shell, which is a case containing hundreds of musket bullets, these are set loose at the desired distance before they reach the devoted body of men, and retaining the forward velocity of the shell, they spread death around like the discharge on the spot of a whole battalion of musketry.

On the awful occasion of a ship in rapid motion being suddenly arrested by a sunken rock, all things on board, men, guns, and furniture, start from their places and are dashed forwards; and the inertia or mortal obstinacy of the stern parts of the ship pressing forward, is sufficient to crush and break the bow against the rock.

"*Motion as naturally permanent as rest.*"

From the instances now given, it is seen that a body at rest would never move if force were not applied, and that a body put into motion retains motion, at any rate for a time, after the force has ceased; but still there is a feeling, from common experience, that motion is an unnatural or forced state of bodies, and that all moving things, if left to themselves, would gradually come to rest.

It is recollected that—a stone thrown comes to rest, or a wheel left moving, or a bowl rolling on the green, or the waves heaving after a storm—and, in a word, that there is no perpetual motion on earth.

On more attentive consideration, however, it may be perceived that there are great differences in the duration of motions, and that the differences are always exactly proportioned to evident causes of retardation, and chiefly to *friction* and the *resistance of the air.*

Friction is the resistance which bodies experience when rubbing or sliding upon each other; and however much it may be diminished by art, it cannot be annihilated. Air resistance, to motions going on in air, is of the very same nature as water resistance, to motions going on under water, only less in degree: and as advancing science has shewn the true nature of our atmosphere, the amount of this resistance is perfectly ascertained.

A smooth ball rolled on the grass soon stops—on a green cloth over a smooth plank it goes longer—on the bare plank longer still—on a sheet of perfect ice, which is smooth and level, it hardly suffers any retardation from friction, and, if the air be moving with it, will reach the shore.

Two little wheels, like windmill wheels, set in motion together with equal velocity, but of which one has the flat sides turned to its course, and the other the edges, if moving in the air, will stop at very different times, but if tried in a vessel from which the air has been removed, they will stop exactly together.

It is to facilitate the motion of fishes, in the water, that they are of sharp form before and behind. And it is for a like reason, that the birds which move in the air have similar form.

A large spinning-top, with a fine hard point, if set in motion in a vacuum, and on a hard smooth surface, will continue turning for many hours.

A pendulum in a vacuum has only a slight friction to overcome at its point of suspension, and therefore vibrates for many hours.

But it is in the celestial spaces that we see motions completely freed from the two obstacles of air and friction—and there they are eternal.

Had the human eye, unassisted, been able to descry the four beautiful moons of Jupiter, wheeling around him for these thousands of years, with such unabated regularity, and which now form, to the telescope of the astronomer, a perfect and magnificent time-piece in the sky—or had science long proved that the velocity imparted to our globe, when first launched into its present orbit, still wheels it along as swiftly as in the days of the first man, this error or prejudice that motion is always tending to rest, would never have arisen.

Indeed, had this and other truths of the same class now known, been long familiar to the common mind, the opposite prejudice would more probably have obtained, that motion is the natural state, and rest a forced or even impossible state. We know of absolutely nothing which is at rest. The earth is whirling round it's axis and round the sun; the sun is moving also round his axis and round the centre of gravity of the solar system, and, doubtless, round some more remote centre in the great universe, carrying all his planets and comets along with him.

The state of the objects around us on the surface of the earth, which surface, near the equator, we know to be revolving with a velocity of 1,000 feet per second, is exactly exemplified, on a smaller scale, by that of the furniture in the cabin of a sailing ship. An admiral sits there, surrounded by his books, and telescopes, and quadrants, and time-pieces, &c.; and seeing them always in the same relative places, he may at last cease to think of his and of their motion; and if he remained there without looking abroad, and the ship had only uniform motion, he would be as insensible of the motion, as men on shore are of the whirling of the earth. It would make no difference in the two cases, whether the ship were sailing one mile or fifteen in the hour, or whether the earth were turning once in twenty-four hours, or, like the planet Jupiter, once in ten.

If there were any natural tendency in moving bodies to stop, a thing floating in a trough of water, on board a sailing ship, should always be found towards the stern; and in all the seas and lakes of the earth, the floating things should be driven upon the western shores, because the surface of the earth is always turning to the east. We know that neither of these suppositions is the truth.

And a man on board a moving ship can throw a ball just as far towards the bow as towards the stern, although in one case the velocity, as regards the earth, will be so different from what it is in the other.

Thus it appears, that whatever *common* motion objects may have, it does not interfere with the effect of a force producing any new relative motion among them. All the motions seen on earth are really only slight differences among the common motions. This explains why men are not sensible of the rapid motion of the earth, all things moving at the same rate; and why a man in the hold of a ship cannot say whether the rushing of water, which he hears from without, be a rapid tide passing, or the effect of the ship's advance in the river; and why, in a ship sailing in smooth water, a man blindfolded, and turned round a few times on his heel, cannot afterwards say whether his face be towards the head or the stern.

A man continuing to throw up a ball or orange, or several of them at once, and catching and returning them alternately, uses no difference of art as regards them, whether he be standing on the earth and whirling with it, or on a ship's deck, or in a moving carriage, or on a galloping horse's back. He and the oranges have always the same forward common motiòn.

The reason that a lofty spire or obelisk stands more securely on the earth than a loose pillar would on the bottom of a moving waggon, is, not that the earth is more at rest than the waggon, but that its motion is uniform.

Ignorance of the law of motal inertia led a story-telling sailor to assert, as a proof of the fast sailing of his favourite ship, that when a man one day fell from the mast-head, the ship had escaped or advanced from under him before he came so low as the deck: the fact being, that he must have fallen on the same part of the deck, whether the ship were in motion or at rest, his body having the motion or rest which belonged to her.

Another wise man, reflecting that the earth turns round once in twenty-four hours, proposed rising in a balloon, and waiting aloft until the country which he desired to reach should be passing under him.

" *Motion naturally uniform.*"

It is only repeating that a body cannot acquire or lose motion without cause, to say that free motion must be *uniform.*

The perfect uniformity of undisturbed motion, is proved by every fact observed in the universe. If any continued motion, as of a planet for instance, be found at one time to have a certain relative velocity to some other motion, the same relation is found always to hold: or deviations from perfect uniformity, are always exactly proportioned to the disturbing causes.

Had motion not been uniform in its nature, man could have formed no rational conjecture or anticipation as to future events; for it is by assuming, for instance, that the earth will continue to turn uniformly on its axis, that he speaks of *to-morrow* and of *next week*, &c. and that he makes all his arrangements for future emergencies: and were the coming day, or season, or year, to arrive sooner or later than such anticipation, it would throw such confusion into all his affairs, that the world would soon be desolate.

To calculate futurities, then, or to speak of past events, is merely to take some great uniform motion as a standard with which to compare all others; and then to say of the remote event, that it coincided or will coincide with some described state of the standard motion. The most obvious and best standards are, the whirling of the earth about its axis, and its great revolution round the sun. The first is rendered very sensible to man by the alternate appearance and disappearance of the sun, and it is called *a day;* the second is marked by the succession of summer and winter, and it is called *a year.* The earth turns upon its axis about 365 times while it is performing one circuit in its orbit round the sun, and thus divides the year into smaller parts; and the day is divided into smaller parts, by the progress of the revolution on its axis being so distinctly marked, in the constantly varying direction in which the sun appears from any given spot on the face of the earth.—When advancing civilization made it of importance to man to be able to ascertain with precision the point of the earth's revolution, connected with any event, various contrivances were introduced for the purpose. The following are among them: sun-dials, where the shadow travels progressively round the engraved and divided circle; the uniform flux of water through an opening, or of sand in the common hour-glass, &c.

But the very triumphs of modern science and art are those astronomical clocks and watches, in which the counted equal vibrations of a pendulum, or of a balance wheel, have detected periodical inequalities even in the motion of the earth itself, and thus have directed attention to disturbing causes, important to be known.

" *Force is required to bend motion.*"

If a body moving freely cannot vary its velocity without a cause, neither can it vary its course without a cause; and free motion, therefore, is *straight* as well as *uniform.*

A ball shot directly up or down gives men their simplest idea of straight motion.

A bullet or arrow, shot horizontally, is gradually drawn downwards by the attraction of the earth, but it swerves not either to the right hand or to the left.

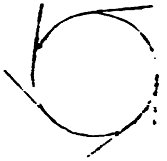
William Tell, trusting to the natural straightness of motion, obeyed the tyrant's order, and shot at an apple placed on his child's head.

And the right eye of Philip of Macedon is said to have been destroyed by an arrow which brought a label on it, telling its destination.

Riflemen hit the very spot on the target which they choose to aim at.

A stone in a sling, the moment it is set at liberty, darts off as straight as an arrow, or a bullet from a gun-barrel, and it is only because the point of its circle from which it should depart, cannot be accurately determined, that the same sure aim cannot be taken with it.

A body moving in a circle, then, or curve, is constrained to do what is contrary to its inertia. On considering a circle as made up of an infinite number of little straight lines, and that the body moving in it has its motion bent at every step of the progress, the reason is seen why constant force becomes necessary to keep it there, and just equal to the inertia with which the body tends, at every point of the circle, to pursue the straight line, called a tangent, of which that point, as seen in the figure,



is the commencement. The force required to keep the body in the bent course is called *centripetal*, or centre-seeking force; while the inertia of the body, tending outwards, that is, to move in a straight line, is called the centrifugal or centre-flying force.

A sling cord is always tight while the stone is whirling: and its tension is the measure both of the centripetal and centrifugal force.

Bodies laid on a table, which is made to whirl like a horizontal wheel, are quickly thrown off.

In a corn-mill the grain is admitted between the stones through an opening in the centre of the upper one; and being then kept turning round between them, it is always tending and travelling outwards until it escape as flour from the circumference.

A man falls asleep or dies of apoplexy, from pressure of blood on the brain, if he lie down on a turning millstone with his head near the edge.

A wet mop, or bottle brush, made to turn or revolve quickly on its handle as an axis, throws the water off in all directions and dries itself.

Sheep, in wet weather, discharge the water from their fleeces by a semi-rotatory shake of the skin. Water dogs, on coming to land, dry themselves by the same action.

A tumbler of water placed in a sling, may be made first to vibrate like a pendulum with gradually increasing oscillation, and may at last be turned round and round the hand without spilling a drop: because the inertia of straightness, or centrifugal force, keeps the water tending more outwards towards the bottom of the tumbler, even when that is uppermost, than it tends to the earth by gravity.

In the same manner as solid bodies laid on a whirling table are thrown off, so water in a vessel which is made to spin round in any way, as on the centre of a horizontal wheel, rises up, against the sides of the vessel all round, instead of lying at the bottom.

Water, poured obliquely into a funnel, runs round the interior of it, and often leaves an open passage of air all the way down through it, as if there were merely a lining of water to the metal funnel. The centrifugal force of the turning water, is a chief reason of this phenomenon. Another reason will be considered further on, under the head of atmospheric pressure.

Whirlpools at sea, and smaller ones, or eddies in rivers, occur whenever a current is obliged suddenly to bend, as in rounding a point of land or a rock. The water, tending to continue its straight motion, falls in behind the obstruction reluctantly as it were, and leaves there, a pit surrounded by a revolving ridge. Charybdis, in the Mediterranean, and the great whirlpool off the Norwegian coast, are remarkable examples.

It is owing to the centrifugal force in any bending part of a stream of water, that when a bend has once commenced, it increases, and is immediately followed by others, until the complete serpentine winding is produced, which characterizes most rivers in their course across extended plains. The water being thrown by any cause to the left side for instance, wears that into a curve or elbow, and the centrifugal force of the water then acts constantly on the outside of the bend, until rock or higher land resist the gradual progress; from this limit it is thrown back again and begins to wear a similar bend to the right, and after that, another to the left, and so on.

Carriages are often overturned in quickly rounding sharp corners. The inertia carries the body of the vehicle in the old direction, while the wheels are pulled round by the horses suddenly into a new one. A loaded stage coach running south, and turned suddenly to the east or west, strews its passengers on the south side of the road, beyond the turning. Where a sharp turning in a carriage road is unavoidable, the outside of the bend should always be made higher than the inside, to prevent these accidents.

A man or a horse, turning a corner at speed, leans much inwards or towards the corner, to counteract the centrifugal force, that would throw him away from it.

In skaiting with great velocity, this leaning inwards at the turnings becomes very remarkable, and gives occasion to the fine variety of attitudes displayed by the expert; and if a skaiter in running begins to incline to one side and is in danger of falling, he merely makes his skait describe a slight curve towards that side, and the centrifugal force of the body, refusing as it were to follow in the curve, restores the perpendicularity. Skaiting to the intelligent man becomes an intellectual, as well as a sensitive or bodily treat, from its exemplifying so pleasingly the laws of motion.

The last example explains, also, why a hoop rolled along the ground goes so long without falling; if it incline to one side, threatening and beginning to fall, by that very circumstance its course is bent, and like the skaiter who bends, it rises again; the bending of its course to that side brings, as it were, its feet again under its body.

A coin dropt on the table or floor, often exhibits the same phenomenon. It is said to run and hide itself in the corner. Before falling, if at a distance from obstruction, it generally makes several revolutions in a small circle.

The reason also why a spinning top stands, will be understood here. While the top is perfectly upright, its point, being immediately under it, supports it steadily, and has no tendency to move from the place; but if it incline at all, the side of the point comes in contact with the floor, and becomes as it were a little wheel or roller, advancing quickly and describing a curve, somewhat as a skaiter does, until it come directly under the body of the top as before.

By reason of the centrifugul force also, it is easier to do feats of horsemanship in a small ring, as at our theatres, than if the animal were running on a straight road. We see the man and horse always inclining inwards, to counteract centrifugal force, and if the rider tend to fall inwards, he has merely to quicken the pace, if outwards, he has to slacken it, and all is well again.

If a pair of common fire-tongs, suspended by a cord from the top, be made to turn by the twisting or untwisting of the cord, the legs will separate from each other with force proportioned to the speed of rotation, and will again collapse when the turning ceases. Mr. Watt adapted this fact most ingeniously to the regulation of the speed of his steam engine. His *steam governor*, may in truth be described as a pair of tongs with heavy balls at the points, attached to a turning part of the machine. If the engine move at all faster than the desired speed, the balls open or fly asunder, with force sufficient to move a valve with which they are connected, and which contracts the steam tube; and on the contrary with too slow a motion, the balls collapse and open the valve.

A half formed vessel of soft clay, placed in the centre of the potter's table, which is always whirling and is called his wheel, opens out or widens, merely by the centrifugal force of its sides, which thus assists the worker in giving the form.

A ball of soft clay, made to turn quickly on a spindle fixed through its centre, soon ceases to be a perfect ball. It bulges out in the middle, where the centrifugal force is great, and becomes flattened towards the ends, near the spindle.

This is exactly what has happened to the ball of our earth, which has bulged out seventeen miles at the equator, in consequence of its daily rotation, and is flattened at the poles in a corresponding degree.

In the planet Jupiter, of which the rotation is much quicker than of our earth, the middle or equator bulges out still more, making the spherical form still less perfect.

A mass of lead, that weighs one thousand pounds at our pole, weighs five pounds less at the equator, by reason of the centrifugal force.

If the rotation of our earth were seventeen times faster than it is, the bodies at the equator would have centrifugal force equal to their gravity, and a little more velocity would cause them to fly off altogether, or to rise and form a ring round the earth, like that round Saturn. Saturn's rings seem to have been formed in this way, and to be now supported chiefly by the centrifugal force of the parts.

It is centrifugal force which prevents the earth and all the planets, while revolving in their orbits, from falling down into the sun.

"The quantity of motion in a body measured by the velocity and quantity of matter."

If a single atom of matter were moving at the rate of one foot per second, it would have the motion expressed by these words; and if it were moving ten feet per second it would have ten times that motion. And if the mass consisted of many atoms, the quantity of motion would be just as much greater, as there were more atoms than one in it.

If a ball of one pound suspended by a cord, as a pendulum, and moving ten feet per second, be allowed to strike against a ball of nine pounds suspended in the same way, but at rest, the two will move on together at the rate of one foot per second, because the original quantity of motion is now diffused through ten times the quantity of matter, and therefore produces only one tenth of the velocity.

A cannon ball of a thousand ounces, moving one foot per second, has the same quantity of motion in it, as a musket ball weighing one ounce, leaving the gun-barrel with a velocity of one thousand feet in the second.

" *The quantity of motion in a body is the measure of the force which produced it.*"

A body falling for ten seconds acquires ten times the velocity which it does by falling for one second only, and its motion is therefore the measure of the force of gravity which has been exerted upon it.

When a large body, or mass of many atoms, falls, it of course has as much more motion than a smaller body, as there are more atoms in it than in the smaller; but as gravity pulls equally at every atom, the force causing either body to fall is still exactly indicated by the quantity of motion in it.

This consideration explains why a mass of many atoms falls just as fast as a smaller body or a single atom. Gravity pulls equally at each atom, and must overcome the inertia of each equally, whether it be alone or with others.

This contradicts a popular opinion, which supposes that a large and heavy body should fall to the earth much faster than a small and light one; and the prejudice has arisen from men constantly seeing such contrasts, as the slow descent of a feather and the rapid fall of a gold coin. The cause of the difference however is, that the atoms of the feather are much spread out, so as to be more resisted by the air than those of the gold: and if the two be let fall together in a glass vessel from which the air has been pumped out, they arrive at the bottom in exactly the same time. If the coin be hammered out into gold leaf, it will fall still more slowly than the feather. One brick let fall from a height, reaches the earth as soon as ten bricks let fall near it, whether these be connected or separate—as a single horse may reach the goal as soon as ten horses galloping abreast.

When a large and a small ship are seen sailing with the same velocity, the surface of canvas or sail, spread to catch the force of the wind, is proportioned to the difference of size and resistance in the two.

A man's force will move a small skiff quickly, a loaded barge very slowly, and a large ship in a degree scarcely to be perceived. In each case, however, the quantity of motion is the same, and still the measure of the force which produced it.

A musket and a cannon ball, each moving a thousand feet in a second, indicate, by the different quantities of motion in them, the difference of the forces which set them in motion—the force of an ounce of gunpowder perhaps in the one case, and of pounds, in the other.

A ball of one pound weight, pulled by a given force, moves twice as fast as a ball of two pounds pulled by the same; but the quantity of motion, as ascertained by the rule already given, is the same in both, although the velocities are different, and it indicates the same producing force.

A mass of a certain weight, turning in a sling or upon a whirling table, requires a certain force to restrain it, in opposition to its centrifugal tendency; a mass of double weight requires double force.

" *And of the force or momentum which it can exhibit again.*" (*See the analysis, page* 48.)

Bodies may be regarded as reservoirs of force or motion, always ready to return as much as they have received.

A cannon ball, according to the quantity of motion in it, may have only the force or momentum sufficient to bruise a plank, or it may have enough to penetrate a tree, or even to shoot its rapid way through a block of the hardest stone.

And substances having the same velocity, but differing in size, and therefore having different quantities of motion, have momenta, or produce effects proportioned always to the quantity of motion.

A small block of wood, floating against a man's leg with moderate velocity, would hardly be felt; but a loaded barge, coming at the same rate and squeezing it against the quay, would break the bones; a large ship, with this speed, approaching the dock-wall, would crush the body of a man caught there; and an island of ice, opposed in its approach to another, even by a first-rate man of war, would destroy this with as little perceivable resistance as meeting barges would destroy a floating egg-shell.

A hail-stone falling strikes rudely; a stone rolled from a height, as of old, by the besieged against the besiegers, may carry death with it to many; an avalanche, breaking from its hold on a mountain steep, may sweep away a whole village.

In meeting bodies the shock is the same, whether the motion be shared between them or be all in one.

If a running man come by accident against a man who is standing, both receive a certain shock. If both be running at the same rate in opposite directions, the shock is doubled, and in some such cases, particularly where swift skaiters have met, the shock has proved fatal.

A man's skull is fractured as certainly by its being dashed against a tree while he is on a galloping horse, as by the blow of a carriage beam, which comes upon him with the like velocity.

The meeting fists of boxers not unfrequently dislocate or break bones.

When two ships in opposite courses meet at sea;

although each may be sailing at a moderate rate, the destruction is often as complete to both, as if with a double velocity they had struck on a rock. Many melancholy instances of this kind are on record. In the darkness of the night a large ship has met a smaller and weaker one, and, all in the lapse of a few seconds, there has been; the shock of the encounter, the scream of the surprised victims, and the horrible silence when the waves have again closed over these and their vessel for ever.—In November 1825, the Comet steam-boat, on the coast of Scotland, was thus destroyed, and carried to the bottom with her about seventy persons, who, a minute before, were far indeed from anticipating the dreadful catastrophe.

" *Direction of the force or forces producing motion.*"

When only one force acts on a body, the body obeys in the exact direction of the force.

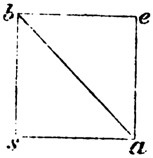
A ball floating in water, or lying on smooth ice, is driven exactly south by a wind blowing south. A bullet issuing from the mouth of a cannon, moves exactly in the direction of the axis of the cannon, which is, as the force pushes it.

When two or more forces act upon a body at the same time, as it cannot move two ways at once, it must hold a middle course between the directions of the separate forces. This course is called the *resulting direction,* viz. resulting from the *composition of the forces.*

A ball or ship moving south by a direct wind, may, at the same time, be carried east just as fast by a tide or current moving east; every instant, therefore, it will go a little *south* and a little *east*, and really will describe a middle line which points *south-east.*

All these particulars may be represented on paper, as by fig. 1:—

Fig. 1.



b being the place of the ball or ship, *e* the east, *s* the south, and *b a* the middle line pointing to the south-east, and shewing the true course of the vessel. This figure is called the *parallelogram of forces*, and is one of the most important helps to the understanding of many facts in natural philosophy. The minute investigation of the subject belongs to the science of measures, or technical mathematics, but the general truths are quite intelligible to common sense, or to the mathematics of common experience.

When two forces act upon a body, like the wind and tide in the last example, the result is the same, whether they act together, or one after the other. For instance, if the wind drive a vessel one mile south, as from *b* to *s*, fig. 1, and immediately afterwards the tide drive it one mile east, as from *s* to *a*, the vessel will be in the same place at last, viz. at *a*, as if she had been driven at once south-east, in the line *b a*, by the simultaneous action of the two. And it is by drawing the lines *b s* and *b e* to represent the force and direction of the two causes of motion, and by then adding one of them, or an equivalent, to the end of the other, as *s a* to *b s*, that the square or parallelogram is formed, of which the middle line, or diagonal, as it is called, shews the resulting direction of the forces, and the true course of the body obeying them.

When the forces exactly cross each other, and are equal, as in the case now supposed, the figure becomes a square, as at fig. 1; but if one of the forces be greater than the other, the figure becomes oblong, as at fig. 2; if the forces cross obliquely, the figure becomes as at fig. 3; and if they cross in an opposing direction, it will be as at fig. 4: but in all the cases, the diagonal shews the *result*;—and it is evident that the same line may be the diagonal of many figures, as seen at fig. 5.

Fig. 2.

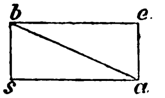


Fig. 3.

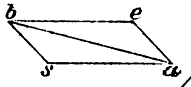


Fig. 4.

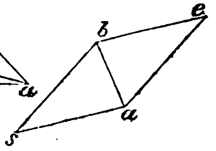
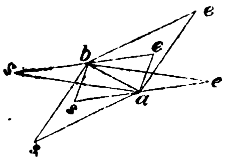
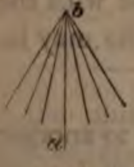


Fig. 5.



In all cases where the two forces are equal, with whatever obliquity they cross each other, the resulting direction must be exactly between them. A boat impelled by oars goes straight, although the extremities of the oars describe curves, because the changing obliquity of the force is always the same on both sides. This explains also why a bird flying, or a man swimming, holds a perfectly straight course, although in both, the direction of the impelling forces is always varying.

And this is the reason why a body suspended, as a plummet, or falling to the earth as an apple does from a tree, is always in a line towards the centre of the earth, because, while the part of the earth immediately under the body is pulling it straight down to the centre, the action of parts on any one side of the perpendicular is exactly counterbalanced by the action of corresponding parts on the other side; and the perpendicular is still the diagonal or middle line of every pair of attracting parts, as seen here in *a b*.



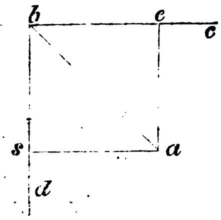
When a body is carried below the surface of the earth, its weight becomes less, because the matter above it is then drawing it up, instead of down, as before: a few hundred feet makes a great difference, and at the centre of the earth, if it were possible for man to reach it, he would find things without weight at all, and there would be no up nor down, because things would be attracted equally in all directions.

Forces crossing each other so obliquely as to be represented by lines in almost opposite directions, would form a parallelogram with scarcely any breadth, that is, the diagonal would approach to nothing; shewing thus, that opposing forces neutralize or destroy each other. In fig. 4, the resulting force or direction is less than either of the constituents.

For the same reason, when forces cross so acutely as to advance nearly parallel to each other, the *resulting* is longer than either. (Fig. 3.)

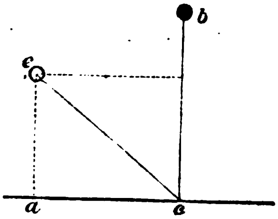
When there are more than two forces acting on a body, the *resulting* direction is found, first of two, and then of the last *resulting*, with each of the other successively. A sailor, to know the true course which his ship has steered, considers, first, the forward progress as found by the log, and then the leeway or sideward motion from a cross wind, and then he combines the result of these with the effect of any tide or current in which he may be sailing.

Resolution of Forces is a phrase pointing to another important use of the figure or parallelogram which has just been described, *viz.* that of enabling us, when any force or motion is given, to find the forces in any other directions, of which such force may be the *resulting* force or motion, and into which it may be resolved.



If a line be given representing a single force, or result of forces, as *b a*, and if it be desired to know how much force there is in this, if wanted to act in another direction, as *b c*, and in another as *b d*, it is only necessary to draw lines in these directions from one end of it, and to complete a square or parallelogram on it, by drawing two lines parallel to the first two from the other end: the lengths of *b c* and *b d*, cut-off by the completing lines, *viz.* *b e* and *b s*, shew the proportions required.

It is thus that a sailor, who knows how far he has sailed in a particular direction, finds out how much he has gone north and east, or south and west; in other words, finds out the difference of latitude and longitude between his present place and a former one.



If a ball *b*, strike a table, *a c*, directly from *b* to *c*, with force represented by the line *b c*, and if it be supposed afterwards with the same velocity to approach the table in the oblique direction *e c*, it will then strike with as much less force than before, as the line *e a* is shorter than *e c*. For, according to the rule for decomposing a force, the line *e a*, drawn here directly towards the table, shews the force which the ball has in that direction.

This explains the important cases of the force of wind on ships' sails, and on windmill vanes; and the force of water on float-boards, and on water-wheels, &c.

" *The two great forces of Nature are* ATTRACTION *and* REPULSION" *(read the analysis, page* 48*).*

A person, on first approaching this subject, is far from supposing that the beautiful and endless variety of phenomena which are seen in the universe around, is all referable to the two principles, attraction and repulsion, which were examined in the first section: but such is the truth. It will first be shewn how the great classes of accelerated, retarded, and bent motions arise from them.

Until Newton said that what we call *weight* of bodies is merely an instance of that universal attraction of matter which diminishes with the distance, it was never suspected that weight was less, high up in the air than on the ground, or on a lofty mountain than on the sea-shore. But that it is so, all accurate observations declare. If the moon were a little nearer to the earth, the tides would rise much higher. In studying, however, what goes on in obedience to gravity near the surface of the earth, except in a few very nice cases, gravity may be considered as a uniform power. Man can neither approach the centre of the earth in mines, nor recede from it in balloons, enough to produce a difference of effect meriting attention in common cases.

" *Accelerated motion, from gravity.*"

Owing to the inertia of matter, any force continuing to act on a mass which is free to obey it, produces in it a quickening or accelerated motion: for as the motion given in the first instant, continues afterwards without any farther force, merely on account of the inertia, as much more motion is added to it during the second instant, and as much again during the third, and so on. A falling body, therefore, under the influence of attraction, is as it were a reservoir—receiving every instant, fresh velocity and momentum.

It is said that Newton's sublime genius read the nature of attraction in the simple incident of an apple falling from a lofty branch, while he was contemplating in his garden. The eye perceives, and can follow an apple beginning to fall, and it can mark the gradual acceleration of its descent explained above, until at last its path affects the sense only as a shadowy line.

A boy letting a ball drop from his hand, can catch it again in the first instant, but after a little delay his hand pursues it in vain.

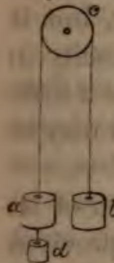
A fragment of rock, detached from the brow of a hill by the lightning stroke, begins its motion slowly: but once fairly launched, it gathers fresh speed and momentum with every instant, and is seen bounding from steep to steep with increasing force, and sweeping every obstacle before it.

Water falling from any reservoir, forms a descending mass or stream, which is smaller below than above, in the proportion in which the velocity increases. This is observed on a mighty scale in the Falls of Niagara; where the river is first seen, bending over the precipice a vast slow moving mass, then gradually becoming a thinner sheet, and flashing into the deep below, with the velocity of lightning.

When velocity becomes considerable in any case of falling, it cannot be measured accurately by the eye, but its effects ascertain it. A man leaps from a chair with impunity, from a table with a shock, from a high window with fracture of his bones, and in falling from a balloon his body is literally dashed to pieces.

The force of gravity or general attraction, is such at the surface of this earth, that in one second it gives to a body, a velocity which, remaining uniform, and without farther action of gravity, would carry it through thirty-two feet in the next second. As this velocity has been gradually acquired, however, the body had only half of it at the half-second, and as much less than half before that time, as it had more than half, afterwards; so that it really falls through only half of the thirty-two, *viz.* sixteen feet in the first second. In the next second, it falls of course through the whole thirty-two feet, with sixteen additional, from the new action of gravity, in all forty-eight, or three times as much as in the first second; at the end of this time the velocity is doubled, or is now sixty-four feet per second, so that in the third second the body falls sixty-four, and other new sixteen, in all, five times as much as in the first second. Knowing this progress, the velocity acquired by a falling body, and the distance through which it falls in any given time, are easily ascertained; and the height of a precipice, or the depth of a well, may be judged of pretty accurately, by marking the time required for a body to fall through the space.

The doctrines of falling bodies are of such importance in the mathematical examination of many of the phenomena of nature, that much attention has been bestowed upon them. Mr. Atwood's ingenious contrivance has enabled experimenters to retard the motion of falling bodies to any desired degree, without otherwise altering its character, and thus has rendered evident to the senses all that abstract calculation in these matters had anticipated. A pound weight falls towards the ground, sixteen feet in the first second, and proves that attraction of one pound has just power to overcome the inertia of one pound at that rate. But if the inertia were doubled, or tripled, or increased in any other degree, the fall of course would be just so much slower. Now Mr. Atwood succeeded in rendering it as great as was desirable for the most accurate observation. He caused his falling weights to overcome not only their own inertia, but also that of other weights. Thus, *a* and *b*, being weights of two pounds each, balancing each other over the pulley *c*, are moved by a weight of one pound, *d*, hooked to one of them, and gravity in pulling this down, with force of one pound, has to overcome, not the inertia of one pound, but of five, for the other two weights must move as fast as the one pound does. Thus the velocity is reduced to one-fifth of what is natural to a falling body, and can be more minutely observed. The experiments with Atwood's machine may be exceedingly varied, and are most interesting.



"*Retarded Motion,*" *from gravity.*

What has been said of the changing velocity of a falling body, from gravity, is exactly true in a reversed way, of a rising body obeying it.

A bullet shot directly upwards, every instant loses a part of its velocity, until at last it comes to rest in the sky, and a soaring eagle might see the messenger of death motionless and harmless for a moment by his side: it would then descend again, and, but for the resistance of the air, would have acquired, on reaching the ground, exactly the velocity with which it had left it: and at corresponding points of the ascent and descent, the velocities would have been equal.

In shooting for amusement at bodies thrown up into the air, it is easy to hit them near their point of turning, and more difficult always as they are nearer to the ground, whether rising or falling.

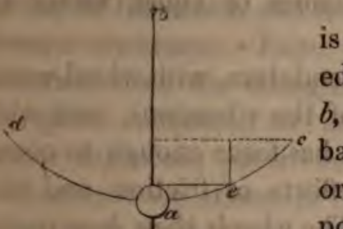
An upward jet of water is small below, where it issues from the pipe with great velocity, but it becomes more bulky as the water loses velocity in ascending, and at the top, it often spreads a little like a palm tree, and any light round solid may be supported upon its summit.

The rise of a pendulum from the bottom of its arc, is an exact copy, reversed, of its previous descent to that point.

Pendulum

is a name applicable to any body so suspended that it may swing backwards and forwards; and when such a body is made of certain form and length, though so simple, it becomes one of the most useful contrivances of man's ingenuity.

Galileo had observed the hanging lamps and chandeliers of lofty ceilings, to continue vibrating with great uniformity, for a long time after any accidental cause of disturbance; and this phenomenon, which in some shape or other had been before the eyes of men from the beginning of the world, when investigated by his genius, led to the most important results. Independently of the light which the theory of the pendulum has thrown on various branches of physics, the thing itself, with a few wheels attached to record its vibrations, has now become the perfect time-keeper, regulating the actions and affairs of men.



A common pendulum is a body, as *a*, suspended from a fixed point, as *b*, and made to swing backwards and forwards, or to vibrate, under this point. Being raised to *c*, and then set at liberty, it falls back to *a* with an accelerating motion, and when arrived there, it has just acquired momentum enough to carry it to an equal elevation on the other side, at *d*; from this it falls back again, again to rise, and it would so go on for ever, but for the impediments of air and friction.—The pendulum is strictly an object of mathematical study: but we shall attempt to give a general idea of its characteristics in common language.

1. The *times of the vibrations* of a pendulum are very nearly equal, whether it be moving much or little, that is, whether it be describing large arcs or small ones. It is this quality which makes it a time-keeper. The reason that a large vibration is performed in the same time with a small one—in other words, that the pendulum always moves faster in proportion as its journey is longer—is, that the larger the arc of the circle described, the

more steep its beginning and ending are, and the more rapidly, therefore, the pendulum falls down at first, and stops at last, and sweeps along the intermediate space. The portion *c e* of the arc is much more steep than the equal portion *e a*. A pendulum made to vibrate in the curve called a cycloid, which differs a little from the circle, has its beats perfectly synchronous or equal, under all circumstances.

A clock is merely a pendulum, with wheel-work, to count the number of the vibrations, and with a weight or spring that has force enough to counteract the retarding effects of friction and the resistance of the air. The wheels shew how many beats of the pendulum have taken place, because at every beat, a tooth of the last wheel is allowed to pass. Now if this has sixty teeth, as is common, it will just turn round once for sixty beats of the pendulum, or seconds, and therefore a hand upon its axis will be the second hand of the clock. The other wheels are so connected with this one, and the numbers of teeth so proportioned, that the axis of one may carry a minute hand, and of another an hour hand.

2. The *length of a pendulum* influences the time of its vibration.

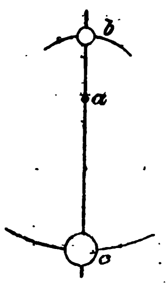
Long pendulums vibrate more slowly than short ones, because, in the corresponding arcs or paths, the long pendulum has a greater journey to perform. If it be twice as long, it has twice as much to fall in its descending half of the arc; but as a body falls four times as far in two seconds as in one, from the acceleration of its motion, therefore a pendulum must be four times as long, to beat once in two seconds, as to beat every second. A pendulum of a little more than thirty-nine inches, beats seconds; one of four times that length is required to beat double seconds, and one of one-fourth the length to beat half seconds. The thousandth of an inch in the length of a pendulum alters the rate of going of the clock, and hence the necessity of extreme accuracy. Even the dilatation or contraction from the changing heat of the seasons, is quite sufficient to affect the motion, and those ingenious contrivances to counteract such influence have arisen in consequence, which are described farther on, in the chapter on *Heat*. Common clocks are regulated by a screw which lifts or lets down the ball of the pendulum. This changes the effective length of the pendulum, which is the distance between the point of suspension, and what is called the *centre of oscillation*, treated of in the next chapter. As all pendulums must be of the same length, to beat in the same time, they constitute an easily found and correct standard of measure.

3. The *force of gravity*, of course, is what determines how long the pendulum shall be in falling to the bottom of its arc, and how long in rising, for the ball of the pendulum may be considered as a body descending on a slope; a change in the force of gravity, therefore, would at once alter the rate of all the clocks on earth. And in reality, as at the equator of our earth, gravity is counteracted, by the centrifugal force produced by the earth's motion, as already explained, a

pendulum goes slower there than elsewhere, and must be shortened in consequence to answer its purpose.

There are many modern astronomical clocks so perfect, that they do not lose one beat of the pendulum in twelve months.

There is a small pendulum called a metronome, used by musicians for marking time; and although very short, it still will beat seconds, or even longer intervals. The reason of its slow motion is, that its rod is prolonged upwards, to *b*, beyond its axis of support at *a*, and there is a ball upon the top, at *b*, as well as on the bottom, at *c*; which upper ball prevents the under one from moving so fast as it otherwise would, just as a small weight attached to one end of a weighing beam, prevents a weight attached to the other, from falling so fast as it would if there were no counterpoise. The rate of motion changes with every change in the position of *b*.



A pocket watch differs from a clock, in having a vibrating wheel instead of a vibrating pendulum; and as, in a clock, gravity is always pulling the pendulum down to the bottom of its arc, which is its natural place of rest, but can never fix it there, because the momentum acquired during its fall from one side, always carries it up to an equal height on the other—so in a watch, a spiral spring surrounding the axis of the moving balance-wheel is always pulling this towards a middle position of rest, but can never fix it there, because the momentum acquired during the approach to it from either side carries it just as far past it on the other side, and the spring has to begin its work again. The balance-wheel at each vibration allows one tooth of the adjoining wheel to pass, as the pendulum does in a clock, and the record of the beats is preserved by the wheels which follow, as already explained for the clock. A main-spring is used to keep up the motion of a watch, instead of the weight used in a clock, and as the spring acts, whatever be its position, a watch keeps time, although worn in the pocket or carried in a moving ship.

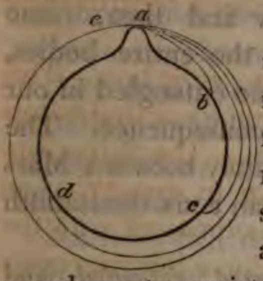
It would be exceeding the limit marked out for this general work, to speak more particularly of those admirable watches which have been produced within the last thirty years under the name of chronometers, for the purpose of finding the longitude at sea; but the author may perhaps be excused for mentioning here, a moment of surprise and delight which he experienced, when he first saw their singular perfection experimentally proved. After months spent at sea, in a long passage from South America to Asia, his pocket chronometer with others on board, announced one morning that a certain point of land was now bearing north from the ship at a distance of only fifty miles; in an hour afterwards, when a mist had cleared away, the looker-out on the mast gave the joyous call of "Land a-head!" verifying the report of the chronometers almost to one mile, after a voyage of thousands. It is allowable at such a moment, with the dangers and uncertainties of ancient navigation before the mind, to exult, in contemplating what man has now achieved—in contemplating the correctness of the sciences, and the perfection of the various arts which contribute to such a result as now related.

Bent or curvilinear motion from attraction.—This takes place whenever attraction is acting across the path of any existing motion. The flying cannon ball or stone, drawn down by gravity, is an example, for the projectile force ceased with the first impulse, but the bending force is acting every instant, and every instant causes a new bend, and thus produces a curvilinear path.

An oblique jet of water is to the eye a permanent exhibition of the curve described by a body thus projected. The separate atoms of the liquid move in the line which they would describe if they had been projected singly, and the continued succession of them marks the line of situations in which each has been or will be before it falls.

A cannon or musket ball, shot quite horizontally, will touch the ground just as soon as a ball dropt direct from the cannon's mouth; for its forward or projectile motion does not at all interfere with the action of gravity. This fact makes strikingly sensible the extraordinary speed of a cannon ball, which has already advanced eight hundred feet in the time that a ball dropt from the hand of a standing person takes to reach the earth. It also explains why, for a long range, the gun must always be pointed more or less upwards.

The minute study of this subject becomes very important to military engineers, and it is known how successfully they have pursued it, by the precision with which they can send their shot and shells to marks at very great distances.



A cannon ball shot horizontally from the top of a lofty mountain, would go three or four miles. (The mountain is represented on an enlarged scale, as standing on the globe, at *a*.) If there were no atmosphere to resist its motion, or if the mountain top were above the surface of the atmosphere, the same original velocity would carry it thirty or forty miles before it fell, as to *b*; with more force still it would reach to *c*, and with still more to *d*. And if it could be despatched with about ten times the velocity of our swiftest cannon shot, it would not have approached nearer to the earth even when it had got quite round to *e* or to *a* again; and its velocity being undiminished, it would be ready to set out on a similar tour. It would thus, in fact, become a little satellite, or planetary body, revolving round the earth. In the successive ranges here supposed, it is seen that the centrifugal force of the ball, or its tendency to move in a straight line, becomes more and more nearly a counterbalance to gravity, and at last is exactly equal to it. If the force given to the ball were more than sufficient to bring it round again to the level of *a*, it would fly off altogether from the earth like a stone from a sling, and would acquire the eccentric motion of a comet. There may really be many such revolving masses above our atmosphere, although invisible to us from their smallness; and it has been supposed by some, that the meteoric stones, which fall every now and then, come from such, or that they are the entire bodies, which have in some way become entangled in our atmosphere, and have fallen in consequence. The four little planets discovered lately between Mars and Jupiter, are not larger than a six-thousandth part of our earth.

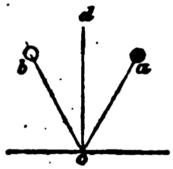
Repulsion produces *accelerated*, *retarded*, and *bent* motions, like attraction, but it acts only at minute distances. *Attraction* draws from the sun, or from the very limits of the universe; while repulsion acts, for instance, between the adjoining atoms of an elastic fluid. Yet repulsion plays a part in the economy of nature, not at all inferior to its sister attraction. We have already seen, when considering the constitution of masses in section first, that repulsion keeps the atoms of bodies from reaching complete contact; that with increase of temperature, it causes these atoms to separate and to form a liquid, or even an air; that it operates around all masses as if it were a film or covering, preventing their mutual cohesion, &c. &c.

Accelerated motion from repulsion, is seen when the atoms of gunpowder explode and propel the bullet from the bottom of the piece to the muzzle, with such rapidly increasing velocity. The strength of this repulsion of gunpowder is so much stronger than the strength of attraction, that its action on a bullet, during the passage along a barrel of five or six feet, will not be overcome by gravity in an ascent of a mile or more.

A visibly *retarded* motion from repulsion, is when a moving body rolls against a bladder full of air, or against the handle of an air syringe, so as to cause the piston to compress the air beneath it.

Any elastic body striking against another and recoiling, exhibits in conjunction the phenomena of retardation, acceleration, and often of bending, from repulsion; for instance:

An ivory ball driven forcibly against a marble slab, does not stop in the instant that apparent contact takes place, but still advances and compresses that part which is against the marble, as is proved by the facts mentioned at page 42. While this compression of the ivory is going on, the resistance made by the increasing repulsion of the atoms gradually retards, and ultimately destroys the forward motion of the ball; and at the instant of its final arrest, the parts in contact, both of the ball and marble, being in their greatest degree of compression, continue to act on the ball and to repel it again with gradually accelerating motion, until it leaves the marble, with the same velocity which it had on approaching it. The retardation and acceleration take place here within so small a space, and in so short a time, that they are not apparent to sense, but the mind perceives the nature of the phenomenon as distinctly as if the ball rolled against the end of a long steel spring and were again thrown back from it. If the ball strike the marble obliquely, it does not rebound in the same line by which it approached, but just as obliquely on the other side of the perpendicular line,



and it then exhibits a bent motion. *a* represents the ball, *c* the point where it strikes the slab, *b* the reflected ball, *d c* the perpendicular.

And if the ivory ball and marble were both perfectly hard, and without elasticity, still the repulsion which surrounds all bodies, as a thin covering, preventing their cohesion, would act exactly as the elasticity of the ivory in the last case, and would cause a retarded motion until perfect rest came, and then an accelerated motion back again, until the ball returned with its primitive velocity.

Collision between hard bodies always exhibits more or less of the truth now described; between soft bodies, as between lumps of lead or of soft clay, the approaching parts mutually displace each other, and there is no recoil.

When a straight steel plate, with its end fixed in a block, is bent, as by a moving ball rolling against it, the atoms on the side which becomes concave are approximated thereby, and there is a resistance or repulsion gradually increasing among them as the spring bends: on the convex side, again, the atoms are drawn a little more from each other than in their natural relation, and are therefore attracting to return, and the recoil of the spring is owing to both forces trying to replace the atoms of the plate in their former relations.

“ *Tides, Winds, &c. are Attraction*” (read the analysis, page 48).

Until we reflect on the subject, we do not perceive that all the phenomena of nature are instances of attraction and repulsion, acting under variety of circumstances.

Tides are raised by the attraction of the moon and sun, and fall again by the general attraction of the earth. They do a great deal of work for man. They carry his ships along the coasts, and up and down his rivers; they turn water-wheels for him; they fill his docks and canals at convenient times; they rise to receive his ships, launched from elevated dock-yards, &c. What a busy scene is a great sea-port river, with the rising and falling of the tide—and the thousands of people all along the banks borrowing its assistance in their various occupations!

Winds are produced chiefly by the attraction of the earth drawing the atmosphere to a level after the action of disturbing causes, such as the heat of the sun, &c. It helps men in their important concern of *navigation*. It turns their windmills, &c.

Currents, as in rivers, are water sliding down slopes, or regaining its level, in obedience to the earth's attraction. Water-mills and inland navigation are among the advantages it yields to man.

All falling and pressing bodies exhibit attraction in its simplest form.

Explosions, steam, springs, &c. are repulsion.

Explosion of gunpowder is repulsion among the atoms when assuming the form of air.

Steam, by the repulsion among its particles, moves the piston of the steam engine, and in our days does half of the work of man.

Accidental explosions of fire-damp, or hydrogen, in mines, and the tremendous evolutions of elastic fluid in volcanoes and earthquakes, are other instances of the same class.

All elasticity, as in springs, collision, &c. belongs also chiefly to repulsion.

A spring is often, as it were, a reservoir of force, kept ready charged for any purpose, as when a gun-lock is cocked, a watch wound up, &c.

It will be remarked, with respect to many of the phenomena now and hereafter to be mentioned, that it is not the original attraction or repulsion which caused the motion, that man uses as his servant, but the momentum gradually accumulated in masses by such attraction or repulsion.

The *magnetical*, *electrical*, *galvanic*, and *optical* phenomena, are also in great part peculiar attractions and repulsions, as will be seen in the chapters devoted to them. And even the *actions of animals*, so infinitely varied, are produced simply by the shortening of the fleshy threads called muscular fibres, through the mutual *attraction* of their component atoms; just as the varied motions of a telegraph, or of a ship's yards, are produced by the action of shortening and lengthening the ropes of connexion.

However closely allied the attractions and repulsions seen in these last-mentioned phenomena, may be to the general attraction and repulsion already treated of, it is found convenient to consider them apart, and they are accordingly reserved for future chapters.

In the remarkable phenomena of nature and art, all caused, as now shewn, by attraction and repulsion, these forces do not operate by a single impulse, but through a repetition of impulses, or a continued action, of which the effect is accumulated in the inertia of matter. Thus all great velocities are the terminations of an accelerated motion.

Meteoric stones, falling from great heights, bury themselves deep in the earth by the force of their gradually acquired velocity.

When the wood-cutters among the Alps launch an enormous tree from high on the mountain side, along the smooth wooden trough or channel prepared for it, in fewer minutes than it traverses miles, it is seen plunging into the lake below; but it acquires its frightful velocity, not at once, but through the action of gravity continued during its descent.

The shock or blow of the ram of a pile-engine, is not the simple effect of the attraction between it and the earth, but of that attraction accumulating its power during the descent of the ram through a space of twenty or thirty feet.

A common hammer, in its instantaneous shock, has the condensed effect of the arm and of gravity, accumulated through its whole previous course; and when a powerful blow is intended, the hammer, or hatchet, or club, or fist in boxing, is lifted high and carried far back, that there may be time and space for imparting greater power to it.

Many actions of the inferior animals are illustrative of the same truth, and prove their experimental or instinctive acquaintance with it.

Sea birds carry shell-fish up into the air, and drop them on smooth stones, to break them, and to obtain the food. It is related in Grecian story that a bird once mistook the venerable bald head of a sage meditating on the sea-shore for a smooth stone, and by the same act killed an oyster and a philosopher.

There are some long-necked birds, that fight and kill their prey, by a blow of their head. They draw back the head, bending the neck like a swan or serpent, and then dart it forward, with a continued effort, until the strong wedge-like beak at last reaches the object, almost with the velocity of a pistol bullet.

Bulls, rams, and goats, in fighting, alternately recede and run at each other, that the shock may be great when the foreheads meet.

A horse in kicking, from the great length of his leg, and the consequent space through which he can be adding velocity, sends his foot at last against the obstacle, almost like a cannon shot.

A bow-string propelling an arrow, follows it for a considerable way, and hence the great velocity at last produced.

A sling gives the hand the power of still adding velocity to the stone when already moving very fast.

The battering rams of the ancients allowed those about them to accumulate in them the efforts of many hands, and of a considerable duration of action, and gave at last one great and sudden shock.

Even the gentle action of the human breath, exerted for a time on a pea or small hard ball of clay, as this passes or is blown through a long smooth tube, gives a velocity which will inflict a sharp and painful stroke on a distant animal. In Borneo and others of the Eastern Islands, poisoned arrows are thrown in this way with great force and precision.

The extraordinary action of gunpowder on bullets, although appearing so sudden, is still not an instantaneous, but a gradual, and therefore accelerating action, and accordingly we find the effect to depend much on the length of the piece along which the force pursues the ball. A small fast-sailing vessel with a single long gun, has often obliged a very superior vessel, whose guns were shorter, to yield.

For the same reason that all great velocities require continued action or repeated impulse to produce them, so do they also to destroy them; the inertia of motion and of rest being exactly equal.

A vast mass of rock suspended like a pendulum, and allowed to sweep down its curve from a considerable elevation, would arrive at the bottom of it, like a battering ram, with force sufficient to shake a thick wall or rampart from its foundation.

The continued action of gravity gave this force, and if, instead of the solid resistance now supposed, and which is not sufficient to take the momentum away, the mass were merely allowed to continue its course and ascend on the other side, the continued action of gravity now opposing its motion, would bring it to powerless rest again by the time it had reached an elevation equal to that from which it fell.

Soft air expanding gives gradually the death-carrying velocity to the cannon ball; and soft air, or cotton, or wool, resisting in a close strong tube, if the bullet could be directed exactly into it, would again gradually stop it. Were the attempt made, however, to stop it suddenly, by a block of the hardest granite, this would be instantly riven by its force.

Bales of cotton or thick yielding cork attached round a ship will receive cannon balls, and bring them to rest, without themselves suffering much, while the naked firm side of the ship would be penetrated. The cotton or cork offers an increasing resistance through a considerable space, while the oak opposes its hard front at once, but only for a moment, and must therefore instantly suffice or be destroyed. A hard body, that it may at once destroy such a motion as we are supposing, must be able to exert as much force in perhaps the space of one-hundredth of an inch, that is, in the extent to which its elasticity will let it yield without breaking, as the moving cause gave, through a very much greater space. When it cannot do this it must be broken or penetrated by the moving body. But the continued opposition of a thick mass of wood, stone, or earth, brings a bullet to rest just as any more elastic opposition would, and gunners have ascertained the exact depth in each to which a ball will penetrate. They call buildings *bomb* or *ball proof*, which have a thickness or depth exceeding this.

A hempen or silken rope supporting the scale of a weighing beam, would resist a greater weight falling into the scale, than an iron chain would, although this were stronger than the rope for the purpose of bearing a quiescent weight: because the hemp or silk would yield by its elasticity, and continue to repeat its resistance through a considerable space, and thus at last would gradually overcome the momentum; while the iron not yielding, would require either to be strong enough to stop the thing suddenly, or would break.

Yet, for the same reason that iron was weakest in the last case, it is stronger as a cable for a ship, than hemp or rope is—because the chain by its weight hangs as a curve or arch in the water, while the rope being nearly of the weight of water, is supported by it and becomes almost a straight line from the anchor to the ship. Now when a great wave dashes against the ship, the rope can only yield by the elasticity of its material, and this is very little, while the chain yields until it be drawn nearly straight, and by this greater latitude of yielding, and therefore length of resistance, it withstands a greater strain.

A great ship moving quickly with the tide or wind could not be stopped instantly by a short chain of any magnitude—something would certainly give way if the attempt were made; but a rope of very moderate size, kept tight between the shore and the ship, and allowed to slip a little from time to time round a wooden block, when the tightness threatened breaking, would arrest her very soon and easily.

The following are farther proofs that forces are to be measured as much by the time or space through which they act, as by their difference of intensity or momentary power.

A door standing open, and which yields readily on its hinges to the gentle push of the finger, is not moved by a cannon ball piercing through it. Now the ball really overcomes here the whole force of cohesion among the atoms of strong wood: but that force is allowed to act or resist for so short a time, owing to the rapid passage of the ball, that it is insufficient to affect the inertia of the door in a sufficient degree to move it. The cohesion of the circle in the door cut out by the ball, would have borne probably a weight of a hundred pounds laid quietly upon it, but being only allowed to act (supposing the bullet to fly twelve hundred feet in a second and the door to be one inch thick) for the 14,400th part of a second, its influence is not perceived. Other examples of the same kind are the following.

A leaden bullet pressed slowly against a pane of glass breaks it irregularly, and just where the strength happens to be least; but the same bullet shot at it from a pistol, makes only a small round hole. It has been amusingly said of such a case, that the particles struck and carried away, have not time to warn the others near them of what is happening.

A cannon ball, having very great velocity, passes through a ship's side, and hardly leaves a mark; while one with less speed splinters and breaks the wood to a considerable distance around. A near shot thus often injures a ship less than one from a greater distance.

A sheet of paper, standing edgeways on a table, is not driven down by firing a pistol ball through it.

The truth at present under consideration also explains, with respect to gun-shot wounds, why a man often remains ignorant for a time that he has been shot, and why a rapid bullet only kills the parts which it touches, while a spent ball may bruise and injure all around.

A circular plate of soft iron, made to turn with extreme rapidity, cuts through the hardest steel file, as a knife cuts through a carrot.

A man lying down and receiving the blow of a great sledge-hammer on his chest, would be destroyed by it; but if a heavy anvil be first laid upon the chest, and the blow be then received upon that, the man bears it with impunity. Here the quantity of motion in the hammer, being diffused through the great mass of the anvil, is reduced to a trifling velocity, and the elasticity of the chest, in its slow yielding, easily overcomes it.

> "*There is no motion or action in the universe, without a concomitant and opposite reaction.*"

It is clear if no action or movement takes place, but in consequence of either attraction or repulsion (and this has now been shewn), that there must always be two objects or masses concerned, and the one must be *attracted* or *repelled* just as much as the other, although with a difference of velocity, of course, proportioned to the difference of size.

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If a man in one boat pull at a rope attached to another, the two boats will approach. If they be of equal size and load, they will both move at the same rate, in whichever of the boats the man may be; and if there be a difference in the sizes, there will be a corresponding difference in the velocities, the smaller boat moving the fastest.

A magnet and a piece of iron attract each other equally, whatever disproportion there be between the masses. If either of the two be balanced in a scale, and the other be then brought within a certain distance beneath it, the very same weight will be required to prevent their approach, whichever be in the scale. If the two were hanging near each other as pendulums, they would approach and meet: but the little one would perform a greater part of the journey, just in proportion to its littleness.

A man in a boat pulling a rope attached to a large ship, seems only to move the boat: but he really moves the ship a little, for a thousand men in a thousand boats, pulling in the same way at the same time, would make the ship meet them at least half way.

A pound of lead and the earth attract each other with the same force; but that force makes the lead fall sixteen feet in a second towards the earth, while the motion of the earth of course is as much less than this, as it is weightier than one pound. It is mathematically true, that even a feather falling lifts the earth towards it.

A spring unbending between two equal bodies, throws them off with equal velocity; if between bodies of different magnitudes, the velocity will be greater in the smaller body, and in exact proportion to the smallness.

On firing a cannon, the gun recoils with as much motion or momentum in it as the ball has; but the momentum being diffused through a greater mass, the velocity is small, and easily checked.

The recoil of a light fowling-piece will hurt the shoulder, if the piece be not held close to it.

A ship in chase, by firing her bow guns, retards her motion; by firing from the stern she quickens it.

A ship firing a broadside heels or inclines to the other side.

A vessel of water suspended by a cord hangs perpendicularly: but if a hole be opened in its side, so as to allow the water to spout out there as a jet, the vessel will be pushed to the other side by the reaction of the jet, and will remain there while it flows. If the hole be oblique, the vessel will turn round constantly.

A vessel of water placed upon a floating piece of plank, and then allowed to throw out a jet, as in the last case, moves the plank in the opposite direction.

A steam-boat may be driven by making the engine pump or squirt water from the stern, instead of moving paddle wheels.

A man floating in a small boat, and blowing strongly with bellows towards the stern, pushes himself onwards with the same force with which the air issues from the bellows pipe.

A sky rocket ascends, because, after it is lighted, the lower part is always producing a large quantity of aeriform fluid, and this escaping, presses on the air below it, but just as strongly on the rocket above, and thus lifts it. The rocket may be said to rise by recoil from continued explosions of gunpowder.

He was a foolish man who thought he had found the means of securing always a fair wind for his pleasure-boat, by erecting an immense bellows in the stern. The bellows and sails acted against each other, and there was no motion; indeed, in a perfect calm, there would be a little backward motion, because the sail would not catch all the wind from the bellows.

A man using an oar, or a steam engine turning paddle wheels, advances exactly with the force that drives the water astern.

A swimmer pressing the water downwards and backwards with his hands, is sent forwards and upwards with the same force by the reaction of the water.

And a bird flying, is upheld with exactly the force with which it strikes the air in the opposite direction.

A man pushing against the ground with a stick, may be considered as compressing a spring between the earth and the end of his stick, which spring is therefore pushing up as much as he pushes down; and if the man were standing and balanced in the scale of a weighing beam, he would find that he weighed just as much less as he was pressing with his stick.

Thus an invalid, on a spring plank or chair, causes the body to rise and fall through a great range, by trifling exertion with the hand on a staff or on a table, and there is the great advantage of almost passive exercise.

When a child cries, on knocking his head against a table or a pane of glass, he is often told, and truly, that he has given as hard a blow as he has received; although, probably, in thinking of results, he blames the table for his head hurt, and his head for the glass broken.

The difference of action, from a fall of one inch or of many, is well known, and the corresponding intensities of reaction are discovered by a man who, in sitting down, is quietly received by a chair, or who unexpectedly reaches the floor where he supposed a chair to be.

When a billiard ball strikes another of equal size directly, it stops, and the second ball proceeds with the whole velocity which the first had.

If a billiard ball be propelled against the last one of a row of balls equal to itself, it comes to rest as in the former case, while the farthest ball of the row darts off with its velocity,—the intermediate ones having each received and transmitted the motion in a twinkling, and without appearing themselves to move.

In every case when two bodies strike against each other, they may be regarded as having compressed a very small strong spring between them; for the natural repulsion of the surfaces is equivalent to such a spring. Owing to this, when a billiard ball strikes another larger than itself, it rebounds, and not only gives to that other all the motion which it originally possessed, but an additional quantity of motion, from the equal action in both directions of the repulsion or spring which causes the recoil. A hammer rebounding from an anvil has given a blow of nearly double the force which it had itself, for the anvil both felt its approach, and, equally with itself, felt the repulsion which caused its return.

What motion the wind has given to a ship, it loses itself, that is, the ship has reacted on the moving air: as is seen when one vessel is becalmed under the lee of another.

Many more interesting facts might be adduced as examples of the equal action and reaction between bodies, but these will suffice.

This second section of the chapter, then, has explained the nature of inertia in matter, and has shewn that the infinitely varied phenomena of motion, which the universe exhibits, are only attraction and repulsion, acting on inertia under diversified circumstances.—And such is the sublime simplicity of the whole scheme of nature!

CHAPTER II.

THE FUNDAMENTAL TRUTHS USED TO EXPLAIN THE PECULIARITIES WHICH ARISE OUT OF THE SOLID FORM OF BODIES:—A DEPARTMENT COMMONLY CALLED *MECHANICS.*

ANALYSIS OF THE CHAPTER.*

Force, which moves part of a solid body, must affect the whole or break off the part.

If the force be directed towards a central point in the mass, it will affect the whole equally, whether to move it, to stop it, or simply to support it. The point is called CENTRE OF GRAVITY, *or* CENTRE OF INERTIA.

In solid bodies moving round an axis, as a wheel or weighing beam does, the various parts are describing circles or performing journeys, which are greater in proportion to their respective distances from the centre of motion. Hence forces, which differ from each other as to speed, may still, through a solid medium, be brought exactly to co-operate or to oppose each other for any length of time; and a slow force will have the same effect as a quicker one, whether to move or to resist, provided that it be more intense in proportion as it is slower. The SIMPLE MACHINES *called* LEVER, WHEEL AND AXLE, PULLEY, INCLINED PLANE, WEDGE, SCREW, *&c. are so many arrangements of solid matter, by which forces of different velocities and intensities may be connected or opposed, and balanced.*

By solid connecting parts also the direction of any existing motion or force may be changed, as when the straight motion of running water is converted into the rotatory motion of a water wheel. Hence the endless variety of COMPLICATED MACHINES.

The perfection of machines and of solid structures generally, depends much on diminishing among moving parts the re-

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* The reader should here re-peruse the general table or synopsis at page first.

sistance which arises from FRICTION, *and on adjusting the forms and positions of all parts to the nature and* STRENGTH OF THE MATERIALS, *and to the strains which they have to bear.*

" *Solid*" is the term applied to a mass in which the mutual attraction of the atoms is so strong, that the mass may be moved about as one body, without the relative positions of the component atoms being thereby disturbed.

" *Force moving part of a solid, must affect the whole or break off the part.*"

This is a necessary consequence of the description or definition of a solid just given. And it follows that in all cases of breaking, the cohesion of the atoms at the fractured part must have been less strong than the weight of the remaining mass, or its inertia, or the force fixing it to its place, or than some combination of these particulars.

The sharp blow of a hammer on an ivory ball, causes it to dart off swiftly, but does it no injury, because the cohesion among the atoms struck is stronger than the inertia of the mass, even under a rapid change: but the blow of a hammer on a large elephant's tusk, indents or breaks the part, because the inertia of the larger mass is stronger than the cohesion of the atoms which receive the blow.

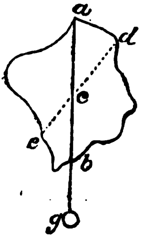
A vessel of pottery-ware may be safely suspended by its handle: proving that the cohesion which fixes the handle to it, is stronger than the weight of the vessel; but if the attempt be made to lift the vessel quickly, the handle may rise and leave the body behind; because then the weight and inertia are acting together. Thus servants attempting to lift too quickly the loaded dishes at a dinner table, often break off the part by which they take hold.

"*Centre of Gravity or Inertia.*"

If a uniform beam or rod be supported by its middle, like a weighing beam, the two ends will just balance each other. This is in accordance with the general truth or law of *attraction* already explained; for as there is just as much matter on one side of the support as on the other, there will also be just as much attraction, and therefore no reason why that on one side should overcome that on the other. If equal weights be afterwards attached to the beam, at equal distances from the centre, the balance will not be thereby disturbed, and for the same reason; and the operation of adding weights that counterpoise, above and below, and near and far from the centre, may be continued, until a bulky mass is built up upon the beam: yet the whole will still remain perfectly supported by the original centre. Now in every body or mass, or system of connected masses, in the universe, there is a point of this kind about which all the parts balance or have equilibrium, and it is this point which is called the centre of gravity or inertia. Although in any mass, therefore, every atom has its separate gravity, and the weight of the whole is really diffused through the whole, still by supporting this one point, either from above or below, the whole mass is equally supported; by lifting it, the whole is equally lifted; and by stopping it, if in straight motion, the whole is equally brought to rest; and when this centre rises or falls, the whole mass is really rising or falling. Thus for many purposes a body, however large, may be considered as compressed into or existing only in this single point, its centre of inertia.

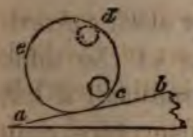
This centre in a mass of regular shape and of uniform substance, as in a ball or cube of metal, is easily found, because it is the evident centre of the mass; but in bodies that are irregular, either as to density or form, it must be found by particular rules of calculation, hereafter explained.

To say that the centre of gravity will always take the lowest situation which the support of the body will allow, is only to repeat, that bodies tend by their gravity towards the centre of the earth. In a suspended body, therefore, as the lowest situation which the centre of gravity can find is, when it is immediately under the point of suspension, all bodies hanging freely must have their centre of gravity directly under this point. A plummet is an interesting example of this; and the truth furnishes a very simple practical mode, in many cases, of finding the centre of gravity of irregular masses.

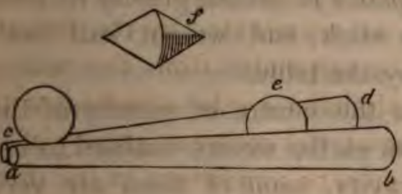


Thus if a piece of plank or of pasteboard, as represented by the figure *a e b d*, be suspended from the point *a*, and a plummet *a g* be attached at the same point, the centre of gravity of the board must be somewhere in the direction *a b*, and a chalk line left on the board where the cord touched it, must pass over the centre of gravity. If the board be then suspended by another point, as *d*, and another chalk line *d e* be made from that point, the place *c*, where the two lines cross or cut each other, will mark the centre of gravity; and the board, when supported by a cord attached there, will hang evenly balanced.

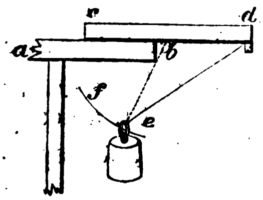
The following cases farther illustrate the truth that the centre of gravity always seeks the lowest place. They seem at first to be exceptions to the law; but when more fully considered, are interesting proofs of it.



A wooden cylinder or roller *e d*, placed on a slope or inclined plane *a b*, will naturally descend, because its centre of gravity is thereby approaching the earth; but if a heavy mass of lead be introduced at one side, as represented at *c*, this must rise before the roller can descend; and the rise being contrary to gravity, the roller will be arrested. Indeed, if it were placed on the plane with the lead in the position *d*, this would fall down to the position *c*, and would move the roller towards *b*: exhibiting the singular phenomenon of a body rolling up hill by the action of its weight.



If a billiard ball be placed upon the small ends of two billiard sticks or cues *a b* and *c d*, which are laid on a table with their points *c* and *a* in contact, but with the larger ends *b* and *d* so far apart that the ball may lie between them, the ball will roll along and down between them until it reach the table near *b*. To a careless observer, it would then have the appearance of rolling upwards, because the cues are thicker towards the ends *d* and *b*; but it would really be descending in obedience to gravity. If a double cone, as represented at *f*, were substituted for the ball, it would still roll from *c* to *b*, and having still more the fallacious appearance of rolling upwards, because its ends would always be resting on the upper and rising surface of the enlarging cues.



The board or stick *c d* resting on the edge of the table *a b* would naturally fall if left to itself, because more than half of it is beyond the table, but a weight *e* attached to it at *b* by the cord *e b*, instead of pulling it down faster, shall fix or steady it, provided the weight be pushed inward a little by a rod *d e* resting against the weight and against a niche at *d*. It is evident that the stick *c d*, in falling, must turn round the edge of the table *b*; but in so doing, from the arrangement now made, it must lift the weight *e* along the path *e f*—which gravity forbids, and therefore the stick and weight will both remain supported by the table.

By attending to the centre of gravity of the bodies around us on earth, we are enabled to explain why, from gravity, some of them are very stable or firmly fixed, others tottering, others falling; for if we find that a body, from its form or position, cannot be overturned without its centre of gravity being lifted, knowing now that thereby the whole mass must be lifted in the same degree, we see why a weak cause cannot effect it.

The rise of the centre of gravity, or body, in any such case, will always be proportioned to the breadth of the sustaining base of the body, compared with the height of its centre of gravity above that base. This is shewn in the annexed figures, in which the two particulars of *base* and *height* are seen combined in various proportions. *c* marks the place of the centre of gravity in the figures, and the curved line beginning from it marks its path when the body is overturned. This curved line is a portion of a circle drawn from the edge or extremity of the base as a centre, (*b*, in fig. A,) because the body must rest upon such extremity in turning, and will make it the centre of motion. The farther inwards, therefore, from this extremity that the centre of gravity is, as marked by a plumb line *p*, hanging from it across the base, the farther of course is the centre of gravity from the top of the circle which it has to describe in moving, and the steeper, consequently, will be its beginning path; and here, as in rolling bodies up slopes, the

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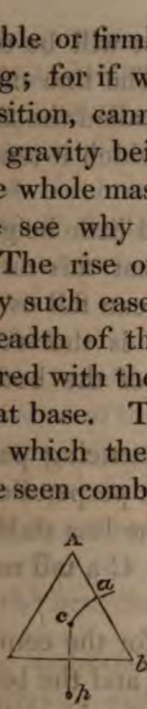

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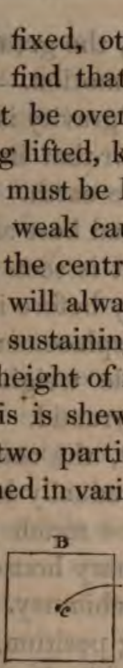

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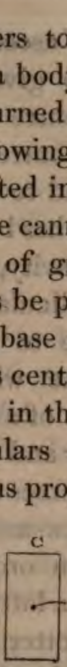

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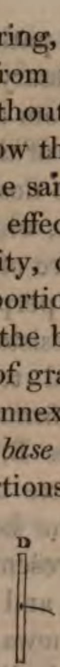

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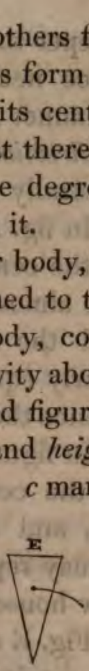
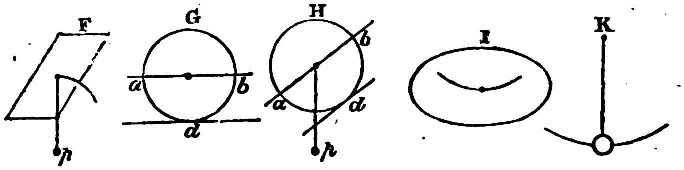


steeper the path of ascent, the greater will be the force necessary to give motion.—The line of a plummet from a centre of gravity is called the *line of direction* of the centre, or that in which it tends naturally to descend to the earth.

In fig. A, which has broad base and little height of the centre of gravity, it is seen that this must rise almost perpendicularly before it can fall over; and the resistance to displacement is therefore nearly equal to the whole weight of the body. Hence the firmness of a pyramid.

In figures B, C, and D, the commencing path of the centre becomes gradually less perpendicular, and the bodies are so much the less stable. B may represent an ordinary house, C a tall narrow house, and D a lofty chimney.

Fig. E shews a tottering position, for the centre of gravity is directly over the base, and the base being only a point, the least inclination places the centre of gravity on a descending slope, and the body must fall.



In F the position is tottering on one side, and stable on the other. This explains how the least inclination of a standing body virtually narrows its sustaining base.

In G, which represents a ball upon a level plane, the whole mass is supported on a single point as completely as in E, and of course the centre of gravity is directly over that point; but although the body be moved, the centre will always be over the point of support or base, and will describe the straight level line *a b*, and has therefore no tendency naturally to move or fall.

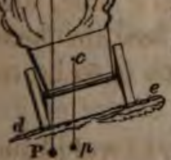
In H the ball is on an inclined plane, and rolls down the centre of gravity, describing the oblique line *a b*.

In I, which is an oval body on a level plane, when moved, the centre of gravity describes the curve seen in the figure, like that of a pendulum. Hence an oval body on a level, rocks or vibrates like a pendulum.

K is a true pendulum whose centre of gravity describes the curve shewn; this was explained in in the first chapter, at page 84.

The importance of the subject of the centre of gravity will be judged of by the facts from nature and art which are now to be reviewed.

A cart-load of metal or stone may go safely along a road inclining to one side, where the same cart loaded with wool or hay would be overturned, because the sustaining base being the same in the two cases, the line of gravity falls much within it from the low centre of gravity of the metal at *c*, while from the centre of gravity of the wool, at *a*, it comes very near the wheel at P, or altogether on the outside, and in the latter case gives a falling path.



For this reason it is that lofty stage coaches or vans are so dangerous, and particularly when heavy luggage is placed upon the top. Lofty gigs and curricles, through which so many accidents happen, may also serve as instances.

In any of these cases, a slight imperfection in the smoothness and level of the road, or even a slight bend of the road in quick driving, suffices to produce the catastrophe.

The safety coaches of late time are made with the wheels farther apart to give broad base, and with the luggage receptacles chiefly low down; while the outside passengers have seats before and behind, and not on the top as formerly.

The feet of a tripod are expanded below to give a broad base. This is also seen in our common chair; but still a thoughtless child often leans so far over the back of a chair, that he causes the line of the general centre of gravity to fall beyond the base, and the chair with its load is overturned. The small lofty chairs made to raise children to the parents' elbow at the dinner table, are very dangerous if the feet are not made to spread much. The pillar-and-claw tables, the candlesticks, the table lamps, and many other articles of household furniture, have stability given by enlargement of the base.

The least inclination of a standing body virtually narrows the supporting base, which is to be calculated only from the line of the centre of gravity to the corner on which the body would turn in falling, as seen at fig. F; hence

The extreme importance of building the thin walls and tall chimneys of modern houses perfectly upright. And hence the extreme importance and utility of that simple implement the plummet or plumb line, which is a visible indication, when applied to a body, of the line of its centre of gravity. The mason and many other workmen cannot proceed a step without their guiding plummet.

The brick walls of modern houses are so thin, that, to have some standing strength, they must rest against and depend upon each other; but they occasionally exhibit the same kind of stability as a child's house built of cards. As contrasted with the masses of masonry which remain to us from antiquity, with the firm-spreading basements which the philosophy of the subject requires, they exhibit that which is truly ephemeral, in opposition to what has partaken of the permanency of nature's own works, and has covered regions with mighty ruins. What magnificent illustrations of strength and durability, arising from proportion, are the ancient pyramids and temples which still give such interest to the banks of the Nile, and to the valleys and plains of Asia.

There are many remarkable structures on earth which lean or incline a little: but, while the line of the centre of gravity remains within the base, and the parts of the mass have tenacity among themselves sufficient to hold together, the structure will stand. The famous tower of Pisa was built intentionally inclining, to frighten and surprise:—with a height of one hundred and thirty feet, it overhangs its base sixteen feet, and has nearly the air of fig. F, in page 114.

The tall monument near London Bridge inclines so much, that in high winds from a particular quarter, timid minds begin to doubt of its stability.

And many of the most lofty and beautiful of our cathedral spires or towers, as that of Salisbury, &c., have lost something of their perpendicularity.

An oval body on a flat level surface, as already explained by fig. I, page 114, vibrates just like a pendulum, because when disturbed from its middle position, its centre of gravity has risen and seeks to return.

The rocking-horse of children and the common cradle are exemplifications of this.

But perhaps the most curious instances of the kind are those rocks called Loggan or Laggan stones, of which there are several among the picturesque barriers of the British coast. An immense mass, detached in some convulsion of nature, is found with a very slightly rounded base resting on a flat surface; and is so nearly balanced that the force of one individual suffices to rock it. Some of these have been objects of much superstitious veneration in their neighbourhood.

There is an amusing Chinese toy, made in obedience to the same principle. It has the appearance of a little fat laughing man, sitting with his feet concealed under him; but instead of feet, the bottom of the figure is a rounded smooth surface, with heavy lead ballast placed so low in it, as, always when allowed, to raise the body to the upright or sitting attitude. A child pushes the little figure down again and again, and is surprised to see it always up the moment after, shaking about and as lively as ever.

The vibratory motion of a pendulum, depending upon the centre of gravity having been moved from its lowest place which it again constantly seeks, was so fully considered in the last chapter, that it need not be again dwelt upon here. Other phenomena of the same class are:—

The vibrations of a common swing.

The rocking of a balloon when it first ascends.

The spontaneous shutting of a gate or door which has been so suspended on its hinges as to hang a little forwards or downwards when in its shut position. Hence it always returns to this of itself, from either side, just as a pendulum returns to the lowest part of its arc.

The rocking or rolling of a ship at anchor, or when sailing in particular states of the wind and sea. When the centre of gravity of a ship is too low, owing to all the heavy load being placed near the keel, this pendulum motion, in rough weather, becomes excessive and dangerous.

The observations now made with respect to the centre of gravity, are beautifully illustrated by the actions and postures of animals, and particularly by those of man.

A body, we have seen, is tottering in proportion as it has great altitude and narrow base—but it is the noble prerogative and distinction of man to be able to support his towering figure on a very narrow base with great firmness. This faculty is acquired slowly because of the difficulty. A child does well who walks at the end of ten or twelve months; while the young of quadrupeds which have a broad support, learn to stand and move almost at once.

The supporting base of a man consists of the feet and the space between them. The advantage of turning out the toes, is that, without taking much from the length of the base, it adds a good deal to the breadth of it.

If there be art in walking on two perfect feet, there must be still greater art in walking on two wooden legs with narrow round extremities. This we see done, nevertheless, by many mutilated soldiers and sailors.

The ladies of the empire of China have to acquire nearly the same talent as these victims of war; for barbarous custom has crippled them all, by confining their feet for life in the shoes which fitted them in infancy.

But surpassing in difficulty any of these instances is the practice of walking on stilts, which is general among the inhabitants of the sandy plains in the south-west of France, called *Les Landes.* These plains afford tolerable pasturage for sheep: but during one season of the year they are half covered with water, and during the other it is most fatiguing to walk upon them, by reason of their deep loose sand and thick furze. The natives lessen the annoyance from all these causes by lengthening their natural legs about five feet, through the addition of the stilts mentioned, which they call *des échasses*. These are wooden poles attached to the legs, and put on and off as regularly as the other parts of the dress. Raised upon them, the people appear to strangers a new and extraordinary race of long-legged beings: they march over the loose sand or through the water without inconvenience, with steps of eight or ten feet in length; their walking speed is that of a trotting horse, and they easily perform a journey of thirty or forty miles in a day. The shepherds, while watching their charge, post themselves in convenient stations, and with a long staff supporting them behind, and their rough sheep-skin cloak and cap covering them above like a thatched roof, they have the appearance of little watch-towers, or singular lofty tripods scattered over the face of the country.

Still beyond the art of walking on stilts, however, is the art which many attain of walking or of dancing on a single rope or wire; or even of keeping the centre of gravity above the base, while standing on the moveable support of a galloping horse's back. The rope-dancer usually carries a long pole in his hand, to balance him; it is loaded at each end, and, when he inclines at all, he throws it a little towards the side required, that the reaction may replace his body where it should be.

Much art of this sort is also shewn in the attitudes and evolutions of the skaiter, in the amusements of supporting a stick upright on the end of the finger, and in many other feats of like kind.

Attitudes generally depend on the necessity of keeping the centre of gravity directly over the base. The following are examples:—the straight or upright port of a man who carries a load on his head;—the leaning forward of one who carries it on his back;—the hanging backwards of one who bears it between his arms;—a man leaning to one side, to balance any weight which he may be carrying on the other;—the habitual carriage of very fat people, with the head and shoulders thrown back, so as to give a certain air of self-satisfaction: the same air belongs to the state of pregnancy, and even to that of the dropsical patient, though producing in it so sad an incongruity.

When a man walks or runs, he inclines forward, so that the centre of gravity may overhang the base in that direction. He must then be constantly moving his feet forward to prevent his falling; and he makes the centre project just enough to produce the velocity which he desires.

A man or inferior animal, in pulling horizontally at a load, is merely causing the body to overhang its base, so that its tendency to fall may become a force or power applicable to the work.

When a man rises from a chair, he is seen first to bend the body forward, so as to bring the centre of gravity over the feet or base, and then he lifts it up. If he lift too soon, that is, before the body be sufficiently advanced, he falls back again.

A man standing with his heels close to a perpendicular wall, cannot bend forward to pick up any thing that lies on the ground near him, without himself falling forward, because the wall prevents him from throwing part of his body backward, to counterbalance the head and arms that must project forward. A man little versed in such matters, offered ten guineas for permission to try, under these circumstances, to possess himself of a purse of twenty, laid before him: he of course lost his money.

When a man walks, the centre of gravity must come alternately over the right and over the left foot. This is the reason why the body advances in a waving instead of a straight line, and why persons walking arm in arm shake each other, unless they make their right and left feet advance together, as soldiers do in their march.

Sea sickness is a subject closely related to the present. Man requiring, as now explained, so strictly to maintain his perpendicularity, that is, to keep the centre of gravity always over the support of his body, ascertains the required position in various ways, but chiefly by the perpendicularity or known position of things about him. Vertigo, and sickness commonly called sea sickness, because it most frequently occurs at sea, are the consequences of depriving him of his standards of comparison, or of disturbing them.

Hence on shipboard, where the lines of the masts, windows, furniture, &c. are constantly changing, sickness, vertigo, and other affections of the same class are common to persons unaccustomed to ships. Many experience similar effects in carriages, and in swings, or on looking from a lofty precipice, where known objects being distant, and viewed under a new aspect, are not so readily recognized: also in walking on a wall or roof, in looking directly up to a roof, or to the stars in the zenith, because then all standards disappear: on walking into a round room, where there are no perpendicular lines of light and shade, as when the walls and roof are covered with a spotted paper without regular arrangement of spot:—on turning round, as in waltzing, or on a wheel; because the eye is not then allowed to rest on the standards, &c.

At night, or by blind people, standards belonging to the sense of touch are used; and it is because on board ship, the standards both of sight and of touch are lost, that the effect is so very remarkable.

But sea sickness also partly depends on the irregular pressure of the bowels against the diaphragm, as their inertia or weight varies with the rising and falling of the ship.

From the nature of sea sickness, as discovered in all these facts, it is seen why persons unaccustomed to the motion of a ship, often find relief in keeping their eyes directed to the fixed shore, where it is visible; or in lying down on their backs and shutting their eyes; or in taking such a dose of exhilarating drink as shall diminish their sensibility to all objects of external sense.

No condition or form of matter escapes from the great laws of nature; therefore we find the attitudes and situations of vegetable as well as animal bodies characterized by the necessity of having the centre of gravity supported over the base.

With what admiration do we contemplate the pine and other trees in the forests of nature, springing up to heaven as perpendicular as if the plummet had been at work to direct them; and this on the brows of precipitous hills as well as in the level plains. On a smaller scale, we see the grasses and corn-stalks of our cultivated fields rising in a similar manner. And whenever, in tree or shrub, accident or peculiarity has caused deviation from this law, additional strength and support are provided in the parts and directions where required.

Beauty of form and position are often found to be the results of bodies having the shape and support required, that the centre of gravity may be stable.

In architecture, how displeasing is a wall or pillar that is not quite upright; or a column with too small a base; or a very tall narrow house; or a long slender chimney, although supported by iron stays. On the other hand, how beautiful in a lofty edifice is the succession of columns from the massive ones which, in the basement, support the whole superstructure, to the light Corinthian or kindred form which is seen above. The Chinese pagoda is a fine example of the union of the requisites for stability, *viz.* perpendicularity and wider base, with the other qualities of perfect symmetry, proportion, and fanciful ornament. When seen crowning a rising ground in a wooded island, or springing up from the centre of a rich garden, it is, perhaps, one of the most beautiful objects which fancy has contrived.

Beauty of attitude and *grace of carriage* in the human individual, are altogether referable to this principle.

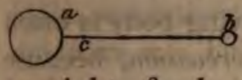
The postures in opera dances might pass as intentional illustrations of the number of ways in which the centre of gravity may be kept above a narrow base, by counteracting one disturbing motion or extension of a limb by some opposite and corresponding motion. And the common statue of the god Mercury on tiptoe is a permanent familiar illustration.

Grace of carriage requires not only a perfect freedom of motion, but also a firmness of step, or constant steady bearing of the centre of gravity over the base. It is usually possessed by those who live in the country, and according to nature, as it is called, and who take much and varied exercise. What a contrast is there between the gait of the active mountaineer, rejoicing in the consciousness of perfect nature; and of the mechanic or shopkeeper, whose life is spent in the cell of his trade, and whose body soon receives a shape and air that correspond to this!—and in the softer sex, what a contrast, is there, between her who recalls to us the fabled Diana of old, and that other, who has scarcely trodden but on smooth pavements or carpets, and who, under any new circumstances, carries her person as awkwardly as something to the management of which she is not accustomed.

The *centre of gravity* is also the *centre of inertia*.

If a person lifts a uniform rod by its middle, he overcomes the inertia of both ends equally, and they rise evenly together. If he lift by a part nearer to one end, the larger and heavier end will rise the last, and there will be a turning motion of the rod round the finger as a centre.

The centre of gravity or inertia need not be the centre of the matter or mass, however; for if a weight of ten pounds, *a*, were affixed to one end of a rod, and a weight of only one pound, *b*, at the other, they would still be balanced, if supported or moved by a point, *c*, ten times nearer to the centre of the large weight, than to that of the small one. This fact is explained under the lever, in the next chapter. In describing such experiments, the weight of the connecting rod itself is neglected for the sake of simplicity.



The *centre of gravity* or *inertia* is also the *centre of centrifugal force*: for if the balls *a* and *b* of the above figure were made to spin round a common centre, as by making the connecting rod rest and turn upon a point or pivot at *c*, the point *c* must be the centre of inertia of the two, or the pivot would be always pulled towards the end of the rod at which there were the greatest centrifugal force. It is on this account that a millstone, or great fly-wheel, or the balance-wheel of a watch, must always have its axis passing through the centre of inertia, for, if not, the axis will soon be much worn on one side.

When we say, in astronomy, that the earth revolves round the sun, or the moon round the earth, we do not speak with absolute correctness; for in all such cases both bodies are revolving round the common centre of inertia of the two. In the case of the sun and earth, as the former is almost a million times larger than the latter, the centre of inertia, being just so much nearer to it, is really far within its body, although not in the exact middle.

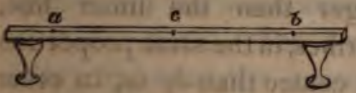
The centre of inertia in a moving body is often called the *centre* of *action* or *percussion*, because if it come against an obstacle, it impels with the whole momentum of the body; but if any other part than the centre hit, the body loses only a part of its motion, and begins to turn round the obstacle as a centre of motion, the momentum of the larger part overcoming that of the smaller.

If a man use a bar or rod of iron as a hammer, he must take care to let it strike the object by its centre of action, or his own hand will receive a part of the shock. This from a very heavy mass might even be dangerous.

In a common hammer, as the chief part of the matter is at the end, and the handle is light, no precaution of this kind is necessary. The centre of percussion is in the heavy end of the hammer.

In the bar of iron now described, and in a pendulum, because the velocity of the different parts varies, and near the far extremity is greatest, the centre of all the motion and inertia is nearer to the fast moving end than to the other. Its exact place is easily ascertained by calculation. In a uniform rod, suspended as a pendulum, this centre is at the distance of one-third from the lower end. It is called the *centre of oscillation.*

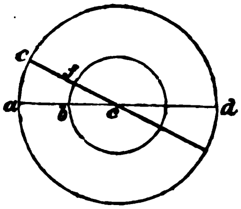
If a rod or small log of wood were floating on water, in a direction east and west, and if a southward blow were given to one end of it, the other end would be found, in the first instant, to have moved a little northward, as if the body had been fixed upon an axis. The inertia of the mass which resists the motion, really becomes as an axis and fixes it. This truth is amusingly illustrated by laying the ends of a long stick on two wine glasses, and then breaking the stick by a smart downward blow of a poker on its centre. Instead of breaking the glasses also by such a blow, the ends of the stick rise at the instant of the stroke, to turn round a certain *centre of resistance* in each of the fragments, and then fall harmless on the table.



In this *section* we have seen what admirable simplicity is given to our reasonings and operations, by considering bodies in many cases in reference only to their *centre of gravity*, or their *centre of action.*

> "*In a solid body moving round an axis, as a wheel or weighing-beam does, the parts have different velocities, according to their respective distances from the axis or centre.*"

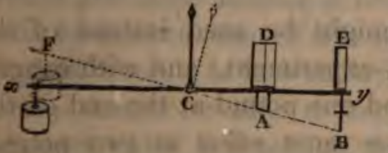
In a solid body in motion, although the atoms or parts must move in connexion, still some of them may be moving over a great space, while others are nearly at rest;—the rim of a wheel, for instance, or the ends of a weighing beam, compared with the parts near the centres. In any body turning on a fixed axis or centre, as now supposed, the spaces through which the different parts move are exactly proportional to their respective distances from the centre. Suppose *a d* to represent the spokes of a wheel, or a weighing beam, with the centre at *c*, the outer circular line which the end at *a* describes when moving, is longer than the inner line, which the part at *b* describes, in the same proportion as *a* is farther from the centre than *b*, or, in other words, as the diameter or radius of the circle *a* is greater than that of the circle *b*: this admits of easy mathematical demonstration. And what is true of the whole circles, is true of any corresponding parts, and, therefore, whether the body turn quite round as a wheel, or only partially as a weighing beam, the rule of velocity equally holds: *a e* is to *b f* as *a c* is to *b c*.



> "*Thus forces with different speed may still be placed in continued connexion or opposition, and will be equivalent if the one be as much more intense than the other as it is slower.*" (*Read the analysis*).

This is the important truth upon which the whole of mechanics may be said chiefly to hinge. It gives to man the *simple machines* or *mechanical* *powers*, as they have been called—those contrivances which enable him to adapt any species and speed of power which he can command, to almost any purpose which is to be accomplished.

We cannot imagine why, to overcome a given resistance, a greater *quantity of force* should be required at one time than at another; and accordingly we find that to move or turn a resisting wheel or beam, through a certain space, the certain quantity of force required may be in the form of a more condensed or intense force to impel a slow moving part, or of a longer and more slender force to act on a part that moves through a greater space; but the same absolute quantity is required in both cases. Ten feet of the action of a heavy ox, near the centre of a great wheel, will be equivalent to twenty feet of the action of a small horse at double distance from the centre. The piston of a steam-engine, in rising six feet, with great force, may be made by intervening machinery to do the same work as one horse would do by drawing six hundred feet, or as one hundred horses by drawing six feet.



Suppose a weighing beam $x\ y$, with a weight of one pound hanging at the end x: if a spring with the force of one pound, and issuing uniformly from the fixed box at E, be made to push at the other end of the beam y, it will just balance the weight; and if it be in the slightest degree stronger than the weight, it will push the end of the beam y down to B, and will raise the weight to F. If, instead of the single spring of one pound at the end of the beam B, two such springs be applied at half way to the centre A, where there is, consequently, just half as much motion, or room to act in, exactly the same effect will follow. Now one spring at the end of the beam is seen here doing the same work as two such springs, or a single spring of double strength, placed in the situation D A: and it would therefore appear that there were a loss of power in one case, and a saving in the other; but let it be remembered, that the two middle springs have each issued by their action only one inch, while the single spring at the end has issued two inches; and in both cases, therefore, there is exactly two inches of pound spring used. This shews, that to overcome the same resistance, the same quantity of force must be used, at whatever part of the moving solid it be applied; only, where a short force is used, it must be so much the more intense, and where a longer one is used, it must be so much the less intense, to answer the same purpose.

Pound weights might be used instead of the springs in the last experiment, and with exactly the same result, and one pound at the end of the arm would have the same effect as two pounds at the middle of it: but it would be observed that the one pound falls two inches, while the two pounds at half distance only fall one inch, and in replacing these weights after they have done their work, it would come exactly to the same thing, whether a person lifted the single pound first one inch, and then another, or whether he first lifted half of the double equipoise an inch and then the other half as much.

Each atom of matter may be considered as held to the earth by its thread of attraction, and if one atom rise or fall ten inches, just as much of the supposed thread of attraction will be drawn out or returned, as if ten atoms rise or fall one inch.

If a man were to exert a force of one hundred pounds at A, in the above figure, to lift the weight two feet, a boy at B with force of fifty pounds might do the same thing; but the man would only have moved down one foot, while the boy would have descended two; therefore, although the boy with the assistance of the lever, seemed to become as strong as the man, it is merely, again, the one-pound spring unbending two inches to effect what a two-pound spring does by unbending one inch. The boy has used two feet of his smaller force where the man used one foot of his greater force; and supposing that each could press through the same number of feet in a day, the boy would have worn himself out when the man was only half tired.—Is it wonderful, therefore, that the boy should be able to accomplish what the man does, with a machine, the construction of which allows him to use twice as much of his smaller power, to move it a certain way, as the man uses with it of his larger power for the same purpose?

If water, falling into buckets on the beam $x\,y$, at

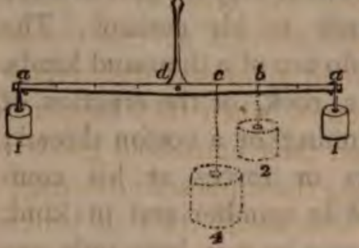
p. 131, were to be used as the power, a two-gallon bucket would be required at D, and only a one-gallon bucket at E, because the same quantity of force being expended in whatever way applied, two gallons descending one foot would be just equal to one gallon descending two feet. In carrying this water back again to its place, it is equal labour to carry the same gallon up the two feet which it has fallen, or to lift each of the two gallons one foot.

It appears, then, from all this, that as the *quantity of motion* in a body is measured by its velocity, and the number of atoms in it conjointly, so the *quantity of force* exerted in any case, is measured by the intensity of the force and the space through which it moves conjointly; and a clear mode of speaking of forces in comparing them, is to state the *lengths* and the intensities—for instance, ten feet of one-pound force, and one foot of ten-pound force.

A horse pulling with a force of fifty pounds goes generally at the rate of six miles an hour, which is upwards of five hundred feet per minute. The steam-engine piston generally moves two hundred feet per minute, and with a pressure of steam of about twenty pounds to each square inch of its surface. A certain mill-stream may turn a wheel with a force of one hundred pounds, at the rate of four hundred feet per minute. Now it is easy, by simple arithmetic, and by the rule of length and intensity now explained, to compare all these forces, and to assign their exact comparative values, when applied to do similar work.

It is the admirable truth, that machines enable man to substitute for each other equivalent forces of different intensities, which may be said to have subjected external nature to his control. The works which he has to do are of a thousand kinds, from the displacing of a rock, or the erection of an obelisk, to the spinning of a cotton thread; but the natural powers or forces at his command are very limited in number and in kind, and in any particular case he may have only one kind at his service: still, being able to connect together his power and resistance by solid media, of which different parts move with different velocities, he can employ any power in work of almost any magnitude or kind. The time required for the work in such cases, will be always proportioned to the disparity in intensity of the power and resistance. Ten hours' work of a little stream of water will be equivalent to one hour's work of a stream ten times as large; or a week's work of one man will equal a day's work of seven men, and so on.

The prejudice on this subject, which it is so important to remove, is, that the simple machines, lever, wedge, screw, pulley, &c., or mechanic powers, as they have been called, are contrivances that really increase the quantity of power or force employed upon them. We shall see most distinctly as we proceed, that they merely enable man to make up, by working longer, for what his strength would be unequal to if applied directly, but they give him no increase in the quantity of power: in other words, they never save labour.



When it is urged, by persons holding this prejudice, that, on a weighing beam or lever, one pound at the end *a*, eight inches from the centre, will just balance the same weight or resistance at the other end, as two pounds placed at *b*, or four inches from the centre, or as four pounds at *c*, or two inches from the centre, and therefore, that the different positions on the beam really make one pound as strong as two pounds or as four pounds: we allow that they are equivalent as balances while the whole remains at rest, but the instant that they are brought to move or to do work, we find (refer to the figure at page 130) that the one pound must fall just twice as far as the two pounds, and four times as far as the four pounds, and a hundred times as far as one hundred pounds, to do the work of these larger quantities, and therefore, that there is precisely the same descent of working matter, or the same quantity of labour in all the cases—in a word, where one pound is made to do any work instead of two pounds, there is no more saving than in giving away two yards of single rope instead of one yard of double rope; and in like manner for all other differences of intensity.

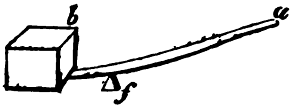
What an infinity of vain schemes—yet often displaying great ingenuity—of perpetual motions and new mechanical engines of power, &c. would have been checked at once, had this truth been generally understood, that no form or combination of machinery ever did or ever can increase, in the slightest degree, the quantity of power applied. No year passes without several patents being taken out for such supposed discoveries; and the deluded projectors, when they happen to be poor, often sell even their household goods to get the means of securing the supposed advantages. Many of them have afterwards died of broken heart, when their attempt, instead of bringing riches and happiness, to their families, has ended in disappointment and utter ruin. The frequency and eagerness and obstinacy with which even talented individuals engage in such undertakings, owing to their imperfect knowledge of natural philosophy, is a remarkable phenomenon in human nature. Examples of such schemes will be noticed in different parts of this work, where they may serve to illustrate points under consideration.

"*Lever, wheel and axle, &c.*" *(Read the analysis at page* 107.*)*

These are the simplest of the contrivances, which the circumstance of solidity in masses, has enabled man to adopt, for the purpose of connecting or opposing forces and resistances of different intensities. We proceed to describe them, and to explain some of their useful applications.

"*Lever.*"

A beam or rod of any kind, resting at one part on a prop or axis, is a lever; and it has been so called probably, because such a contrivance was first employed for lifting weights.



This figure represents a lever used to move a block of stone: *a* is the end to which the *power* or *force* is applied, *f* is the *prop* or *fulcrum*, and *b* is the *weight* or *resistance*—in this case a mass of stone. According to the rule already given and explained at page 126, the power may be as much less intense than the resistance, as it is farther from the fulcrum. A man at *a*, therefore, twice as far from the prop as is the centre of gravity of the stone *b*, will be able to lift a stone twice as heavy as himself; but he will only lift it one inch for every two inches that he descends: and it would require two men acting at half the distance, to do the same work.

The figure at page 136 is also of a lever, and there it has the shape of a weighing beam. *a* and *a* represent pound weights balancing each other at equal distances from the centre of the beam or fulcrum. If a two pound weight *b* were substituted at half the distance from the centre in place of the one pound—or a four pound weight *c*, at one-quarter of the distance, the balance would still remain.

There is no limit to the disparity of forces (as to intensity) that may be placed in opposition to each other by the lever, except the length and strength of our trees, from which the levers must be formed. A force which is one hundred times as far from the centre of motion as the resistance, will balance a resistance one hundred times as intense as itself; but in moving, it must pass through one hundred times more space. Archimedes said, and said truly, " give me a lever long enough, and a prop strong enough, and with my own weight I will move the world." But he would have required to move with the velocity of a cannon ball for millions of years, to alter the position of the earth by a small part of an inch. Science had not yet shewn, that this feat of Archimedes is performed by every man who leaps up from the ground, for he really kicks the world a little way from him when he rises, and attracts it again when he falls back.

To calculate the precise effect of a lever in practice, it is always necessary to take into account the weight of the lever itself and its bending; but in speaking of the theory of the lever, it is usual to disregard this, and, for the time, to consider it as a rod without weight and without flexibility.

The rule for the lever, that opposing forces, to balance each other, must be more or less intense, exactly as they act nearer to or farther from the centre, holds in all cases, whether the forces be on different sides of the prop, or both on the same side, and whether the force nearest to the prop have the office of power or of resistance.

The following are examples of levers with the prop between the forces.

The handspike, represented in p. 138 as moving a block of stone. The same form is called a crowbar when made of iron, and with its extremity formed into claws. Both of these are used much by gunners, in the working and placing of cannon during battle; they are also used generally for lifting and moving heavy things through small spaces, as the materials of the mason, the shipbuilder, the warehouseman, &c. Housebreakers use a short crow-bar for wrenching locks open, tearing off hinges, &c.

The common claw hammer, for drawing nails, is another example. A boy who cannot exert a direct force of fifty pounds, may yet by means of a hammer extract a nail to which half a ton might be suspended, because his hand moves through perhaps eight inches, to make the nail rise one-quarter of an inch. The claw-hammer also proves, that it is of no consequence whether the lever be straight or crooked, provided it produces the required difference of velocity between power and resistance. The fulcrum of the hammer is the part resting on the plank.

Pincers or forceps are double levers, of which the hinge is the common prop or fulcrum. In drawing a nail with steel nippers, one has a good example of the advantages of using a tool: 1, the nail is seized by teeth of steel instead of by soft flesh. 2, instead of the force of the extreme fingers only to gripe it, there is the force of the whole hand conveyed through the handles of the nippers. 3, the force is rendered perhaps six times more effective by the lever length of the handles. And 4, by making the shoulder of the nippers a fulcrum in drawing the nail, it acquires all the advantages of the claw hammer for the same purpose.

The obstetric forceps is an example of this class, which the professional man requires to study attentively. The blades are not fixed to each other permanently as in common forceps, but rest on, or hook into, each other when required.

Common scissors are also double levers, as are those stronger shears, with which bars and plates of iron are now cut under the power of a steam engine as readily as paper is cut by the hand.

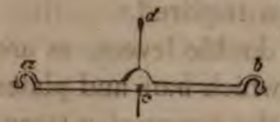
The common fire poker is a lever. It rests on the bar of the grate as its prop, and displaces or breaks the caked coal behind as the resistance.

The mast of a ship, with sails set upon it, may be regarded as a long lever, having the sails as the power, turning upon the centre of buoyancy of the vessel as the fulcrum, and lifting the ballast or centre of gravity as the resistance. For this reason lofty sails make a ship heel or lean over greatly, and become dangerous in open boats.

In some of the islands in the Eastern and Pacific Oceans boats are used extremely narrow and sharp, that they may sail swiftly; and to counteract the overturning tendency of their large sails, they have an outrigger or projecting plank to windward, on the extremity of which several of the crew sit as a balance.

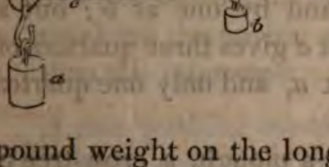
Perhaps no instance of the lever, with the prop between the forces, is more interesting than the weighing beam: whether it be that with equal arms forming the common scale beam; or that with unequal arms, forming the steelyard.

We have seen why quantities attached at equal distances from the prop, must be equal to each other to balance. A lever, therefore, enabling us to place quantities thus exactly in opposition to each other, and turning easily, becomes a weighing beam. The annexed figure shews a common form. Those made for philosophical purposes are so perfect and delicate, that they turn with the weight of a small part of a grain. The axis or pivot of a weighing beam is sharpened below, wedgelike, that its centre may be nicely determined, and that it may turn easily. In a delicate balance, the axis is almost as fine as a knife edge. It rests on some fit hard smooth surface of support. The scales are suspended also by sharp edges, to determine nicely the points of suspension, and to facilitate motion. The length of the arms must be perfectly equal, otherwise a smaller quantity on the long arm will balance a larger quantity on the short one. There have been unprincipled shopkeepers, who have purposely had that arm of their balance to which the merchandize was attached, a little longer than the other, and thus a smaller quantity than due, lifted the weight: half an inch difference, in a beam arm of eight inches, would cheat the buyer of exactly one ounce in every pound. The cheat is to be detected instantly, by changing the places of the two things balanced: for thus the lightest will be at the short arm, and will then be doubly too light. To try any beam, we must first balance two things on it perfectly, and then transpose them. For very delicate purposes, the line of the fine edge on which the beam turns must pass through the centre of gravity of the beam, for if



the centre of gravity be below the support, it will be to the beam what ballast is to a ship, and will keep the beam horizontal, with force requiring a certain weight to turn it. If the centre of gravity, again, were above the centre of motion, the beam, once inclined, would fall over, and could not recover again of itself. In common beams, the centre of gravity is always below the line of support, that the balance may hang horizontally, and may quickly return to its bearing.

There is a mode of arriving at very accurate results, even with a weighing beam which is not itself accurately made, provided it turn easily on its axis; and it is this: first to balance the thing to be weighed very nicely in one scale, and then removing it, to put weights into the same scale, until a perfect balance is again produced. These weights are the exact equivalent or weight of the substance under examination, however unlike to each other the arms of the balance may be.



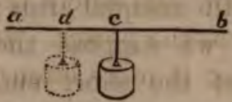
The steelyard is a lever with unequal arms; and if we suppose the hook of the short end to be one inch from the centre of support *c*, a pound weight on the long arm will always balance as many pounds suspended at the short arm as the pound is removed inches from the fulcrum. This supposes, however, that the bare steelyard hangs horizontally, from having a greater mass at the short end to balance the long slender limb from which the weight hangs. In the figure, one pound is seen balancing four pounds.

The Chinese, who are so remarkable for the simplicity to which they have reduced their common implements, weigh all small objects by a delicate steelyard. It consists of a rod of about six inches in length, having a silk cord attached to a particular part, to serve as a fulcrum, and with a sliding weight on the long arm, and a small scale on the short one.

Examples of levers with both forces on the same side of the prop, the force farthest from the prop being the power.

A common wheel-barrow; in using which a man bears as much less than the whole weight of the load, as the centre of gravity of this is nearer to the wheel than to him.

Two porters carrying a load between them on a pole, share it equally, if it be in the middle between them; but if it be more towards one end, he to whom it is nearest carries as much more than the other as the load is nearer to him. A load at *c* is equally borne by a porter at *a* and by one at *b*; but a load at *d* gives three quarters of its weight to the man at *a*, and only one quarter to him at *b*.



When two horses draw a plough, a cross-tree is used, with the middle hooked to the plough, and a horse attached to each end. The two must thus pull equally to keep the tree directly across. If three horses are wanted to pull, in heavy land, the farmer attaches two of them to one end of the cross-tree, but he then attaches it to the plough by a hook twice as near to one end as to the other.

The oar of a boat is a lever of this kind, although the fulcrum is the unstable water.

The common table nutcrackers also, by the lever power of which a person can break a shell ten times as strong as with the bare fingers.

We here also see the reason why a finger caught near the hinge of a door when shutting, is so much injured. The centre of action of the door is moving through a great space comparatively, and is acting with a great lever advantage on a resistance placed where the lever is moving very slowly. Children often pinch their fingers in the same way in the hinge of the fire-tongs, and wonder why the bite is so keen.

The phenomenon of the branch of a tree giving way, when overloaded with snow in winter, or with fruit in autumn, also exhibits the action of this kind of lever. The resistance is the cohesion of the branch to the tree, where it first cracks, and the fulcrum is the last part that remains unbroken.

Examples of the lever, where the two forces are on the same side of the pivot, and where the one nearest to the pivot acts as the power. In this kind the power, of course, is more intense than the resistance.

A man pushing open a gate while standing near the hinges, moves his hand a much less way, than the end of the gate.

When a man uses the common fire-tongs, the ends move much farther than his fingers, and with proportionately less strength; and no one fears a pinch with the ends of the fire-tongs.

But the most beautiful and remarkable instances of this modification of lever are in the limbs of animals. The object in these was to give to the extremities great range and freedom of motion, and still to have no uncouth cross cords like bowstrings running between the parts. This has been obtained most perfectly, by inserting the moving tendons or ropes near to the joints, which are the pivots or fulcra of the bone levers.

In the human arm, the deltoid muscle, which forms the cushion of the shoulder, by contracting its fibres one inch, will raise the elbow twenty inches; and of course, if it raise it so as to lift at the extremity a weight of fifty pounds, it must itself be acting with a force twenty times as intense, or with one thousand pounds.

What extraordinary force of muscle is displayed, then, by that man who lifts another at the end of his extended arm; yet some men do this with ease, and even on both sides at once.

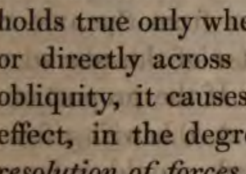
How powerful must be the wing muscles of those birds, that by this kind of action sustain themselves in the sky for many hours together. The great albatross, with wings extending fourteen feet or more, is seen in the stormy solitudes of the Southern Ocean, accompanying ships for whole days without ever resting on the waves.

Two inches' contraction of the glutei muscles of the hip, gives to the human step a length of four feet.

While it was the erroneous opinion that machines really increased power, instead of merely accommodating forces to purposes, this last kind of lever, where a great force acting through a short distance is made to give great extent of motion and other benefits, was regretted by many as a most unprofitable contrivance, and it was called the *losing lever*.

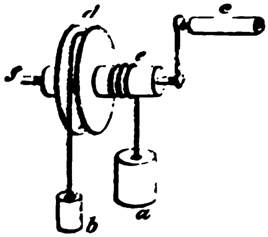
It is almost unnecessary to say, that the same rule of comparative velocities ascertains the relations required in power and resistance where a combination of levers is used, as where there is only one. If a lever which makes *one* balance *four*, be applied to work a second lever which does the same, one pound at the long arm of the first will balance sixteen pounds at the short arm of the second lever.

The general rule for the lever, that a force may be less intense the farther it is from the pivot, holds true only when the force acts at right angles, or directly across the lever; for if there be any obliquity, it causes a corresponding diminution of effect, in the degree explained under the head of *resolution of forces*, at page 76. For instance, one pound at *b* on the end of the long arm of the bent lever *b d a*, because its weight does not act directly across *b d*, has influence only as if it were acting directly at the end of the shorter horizontal arm *f d*; and the two pound weight at *a* acts only as if it were on the horizontal arm at *e*; now as *e* is only half as far from the centre as *f*, two pounds at *a* will just balance the one pound at *b*. In every case, the exact influence of weights may be known by referring them to places directly above or below them, on a supposed horizontal lever *e f*. What is called a *bent lever balance*, is made on this principle. It has on

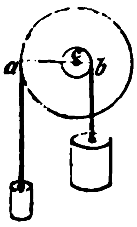


one side a heavy weight at *a*, and on the other side a scale attached at *b*; and the weight of any thing put into the scale is known by the distance to which *a* is moved from the support *c d* before equilibrium is produced. This distance is always exhibited by the line *e d*.

" *The wheel and axle* "

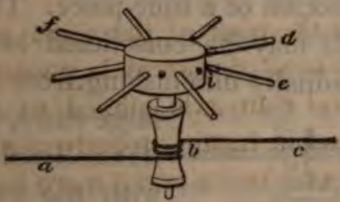


is the next of the *simple machines*. *d* represents a wheel, and *e* an axle affixed to it; and in turning together, it is seen that as much more rope would be unwound from the wheel than from the axle as the diameter of the one were greater than that of the other. If the proportions were as four to one, one pound at *b*, hanging from the circumference of the wheel, would balance four pounds at *a*, hanging from the opposite side of the axle.



This figure represents the same object as the last, only as it would appear if viewed endways, and it explains why the wheel with its axle has been called a perpetual lever. The two weights hanging in opposition, on the wheel at *a*, and on the axle at *b*, are always as if they were connected by a lever *a c b*, turning on the centre *c* as its prop: and while a simple lever could only lift through a small space, it is evident that this construction will lift as long as there is rope to be wound up.

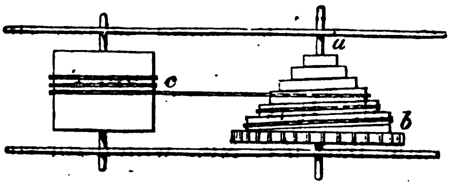
A common crane for raising weights, consists of an axle winding up the rope which carries the weight, and of a large wheel, to the circumference of which the power is applied. The power may be either the effort of the hand, or the weight of a man or inferior animal walking in the inside of the wheel, and moving it as a squirrel moves the cylinder of its cage.



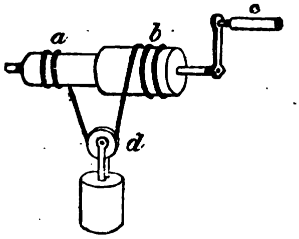
The capstan, on board of ships, is merely a large upright axle or spindle *b*, round which the cable or other rope *a b c*, may be wound. It is turned by the men pushing at the capstan bars *d e*, &c., which for the time are stuck into holes made for them in the broader part or drum at the top of the spindle. The bars may be considered as the spokes of a large wheel, and the effect produced by a man working at one of them is in proportion to his distance from the centre. The capstan is chiefly used on board-ship, for lifting the anchor, and for doing any other very heavy work; but it is also very useful on shore.

The common winch, represented as attached to the wheel and axle in the preceding page, at *c*, with which a grindstone is turned, or a crane worked, or a watch wound up, is really in principle a wheel: for the hand of the worker describes a circle, and it makes no difference whether an entire wheel be turning with it, or only a single spoke of a wheel.

That part of a common watch called the *fusee* is as beautiful an illustration of the principle of the wheel now under consideration, as it is a useful and ingenious contrivance. The spring of a watch, immediately after winding up, being more bent, is acting more powerfully than it does afterwards when slacker; and were there no means of equalizing the action, it would destroy the wished-for uniformity in the motion of a time-piece. The fusee is this means. It may be considered as a barrel or spindle, gradually diminishing from its large end *b*, to its small end *a*, with the surface cut into a spiral groove to receive a chain. The spring which is in the box *c* moves the watch by pulling at this chain. Now when the watch has just been wound up, the fusee is covered with the chain up to the small end *a*, and the newly bent and strong spring begins to pull by this small end or short lever; afterwards, exactly as the spring becomes relaxed and weaker, it is pulling always at a larger and larger part of the fusee barrel, and therefore is always producing an equal effect on the general movement.

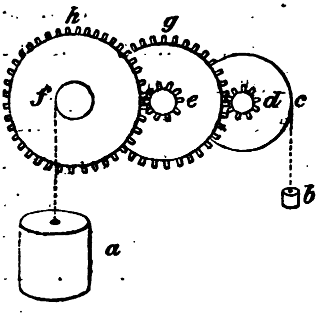


A large fusee is often used in place of a common axle, to a winch, for drawing water by a bucket and rope from very deep wells. When the bucket is near the bottom of the well, the labourer has to overcome the whole weight of the long rope, in addition to that of the bucket and water, and does it more easily by beginning to wind on a small part of the axle.



By the double axle *a b*, very unequal intensities of force may be balanced. It is seen that in turning it, a rope unwinding from the small end *a*, is taken up by the large end *b*, turn for turn, and the rope below is shortened at each turn by the difference between the ends. If the weight rise half-an-inch only, while the handle of the winch describes a circle of fifty inches; one pound force at the winch, would balance one hundred pounds at *d*.

When a wheel is made very large, or an axle very small, although thus forces of very different intensities may be balanced, still the machine becomes of inconvenient proportions; and it is found preferable, when a great difference of velocity is required, to use a combination of moderate-sized wheels instead of one which is very large.

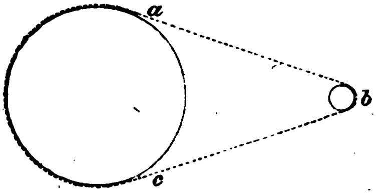


In this figure three wheels are seen connected together. Teeth on the axle *d*, of the first wheel *c*, act on teeth in the circumference of the second wheel *g*, and turn it once for every six times the *c* turns; and in the same manner the second wheel, by turning six times, turns *h* once, and therefore the first wheel turns thirty-six times for one turn of the last; and as the diameter of the wheel *c*, to which the power is applied, is three times as great as that of the axle *f*, which has the resistance: three times thirty-six, or one hundred and eight, is the difference of intensity between weights or forces that will balance here.—The axle with teeth upon it, as *d* or *e*, is called a pinion.

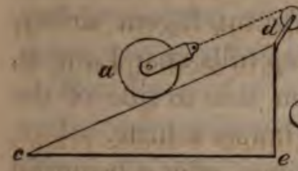
On the principle of combined wheels, cranes are made, by which one man can lift many tons. It would even be possible to make an engine, by means of which a little windmill, of six inches diameter, should be enabled to tear up the strongest oak by the roots; but of course it would require a very long time for its work.

The most familiar instance of wheel-work is in our clocks and watches. One turn of the axle on which the watch-key is fixed, is made equivalent to about four hundred turns or beats of the balance wheel, and the exertion of the hand which winds up, during a few seconds, is thus sufficient to give motion for twenty-four or thirty hours. By increasing the number of wheels, a time-piece is made, which will go for a year: one might be made to go for a hundred or a thousand years.

Wheels and axles may be connected by bands as well as by teeth, as is seen in the common spinning wheel, in turning lathes, grindstones, &c. &c. A spinning wheel of thirty inches circumference, as *a c*, turning by its band, a pirn or spindle of half an inch, *b*, turns this sixty times for every turn of itself.



"*The inclined plane*"



is the third means, which we shall describe, of balancing forces of different intensities, by solid media. A force pushing a weight from *c* to *d*, only raises it through the perpendicular height *e d*, while it acts along the whole length of the plane *c d*; and if the plane be twice as long as it is high, one pound at *b*, acting over the pulley *d*, would balance two pounds at *a*, or any where on the plane: and so of all other quantities and proportions.

A horse drawing on a road where there is a rise of one foot in twenty, is really lifting one-twentieth of the load, as well as over-coming the friction and other resistance. Hence the importance of making roads as level as possible; and hence the folly of our forefathers, in often carrying their roads directly over the tops of hills, for the sake of the straightness considered vertically, while by going round the bases, they might have saved distance, and would have avoided all rising or falling. Hence, also, in making a road up a very steep hill, instead of carrying it directly up, it is made to wind or zig-zag all the way: for the height of the mountain remaining unchanged, the ease of the pull to the horses is increased exactly as the road is made longer. This rule of road-making is exhibited remarkably on the almost perpendicular faces of some of the hills in the island of St. Helena; where, exceedingly safe and commodious roads have been constructed, leading to the forts and residences near the summits. An intelligent driver, in ascending some of the steep hills near London, on the old roads, winds from side to side of the road all the way, to save his horses a little.

The railways of modern times offer a beautiful illustration of this subject. They are made either perfectly level, so that the drawing horse or steam engine has only to overcome the friction; or where heavy loads are only passing one way, as from mines, they are made to slope a very little, so as to save the labour of the steam engine altogether, and to require one horse only to regulate the movement.

Hogsheads of merchandize, which twenty men could not lift, are often seen moved out or into waggons, with the assistance of inclined planes, by one or two men. In some canals, the boats are drawn up by machinery on inclined planes, instead of being raised in locks, as is more usual.

It is supposed that the ancients (the Egyptians particularly) must have used the inclined plane, for the purpose of transporting and elevating the immense masses of stone which still remain from their times as pillars and obelisks.

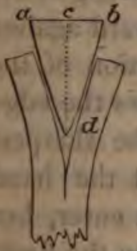
Our common stairs are inclined planes in principle; but, being so steep, are cut into horizontal and perpendicular surfaces, that there may be a firm footing.

A body falling freely, in obedience to gravity, descends about sixteen feet in the first second, as already explained at page 80. If made to roll down an inclined plane, it goes just as much slower than this, as the length of the plane is greater than its height. In a plane rising one foot in sixteen of its length, a body would roll down only one foot in a second.

The descent of a pendulum in its arc is investigated mathematically by the law of the inclined plane, which it exactly obeys.

And the law of the inclined plane itself is mathematically examined by the principle of the *resolution of forces*, explained at p. 76.

" *The wedge* "



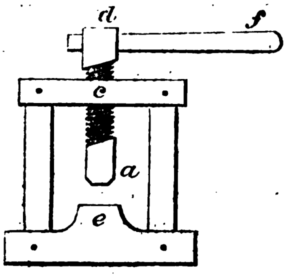
is merely an inclined plane, or two together, pushed in between resistances to overcome them, instead of, as in the last case, the resistance being moved along the plane: and the same rule explains the principle of both. In pushing or driving a wedge into its place, the force may be considered as moving through a space equal to the *length* of the wedge *c d*, and the resistance is separated by a space equal to the thickness of the wedge or *a b*.

But this rule is far from explaining the extraordinary power of a wedge. It appears, that during the tremor of the particles, produced by the blow of the driving hammer, the wedge point insinuates itself, and advances more quickly than the above law anticipates.

The wedge is used to split blocks of stone and wood, and sometimes to squeeze strongly, as in the oil press. It is also used to lift great weights, as when a ship of war in dock is raised by driving wedges under the keel.

An ingenious engineer in London, who had built one of those very lofty and heavy chimnies required for steam engines, &c., found some time after that it was beginning to incline, owing to the dampness of the foundation. He succeeded, however, by driving wedges under it on one side, to restore it to perfect uprightness.

Nails, awls, needles, &c. are examples of the wedge; as also all our cutting instruments, as knives, razors, the axe, &c. Some of these latter are used somewhat in the manner of a saw, which is a series of wedges, by pulling them along at the same time that they are pressed forward against the object. It appears that the vibration of the particles produced by this action allows the edge to insinuate itself more easily, for the sharpest razor may be pressed *directly* against the hand with considerable force, and will not enter, but if drawn along ever so little, it darts into the flesh.



“ *The screw* ” is another contrivance of the same class. It may be called a winding wedge, for it has the same relation to a straight wedge that a road winding up round a tower has to a straight road of the same length and acclivity.

A screw may be described as a spindle, with a thread wound spirally round it; and it turns or works in a nut, which has a corresponding spiral furrow just fitted to receive the thread. Every turn of the screw, therefore, carries it forward in the nut, or draws the nut along upon it, by exactly the distance between two turns of its thread. This, therefore, is the space described by one of the forces (generally the resistance); and the other moves in the circumference of the circle described by the handle of the screw. The disparity between these lengths is often as one hundred or more to one; hence the prodigious effects which a screw enables a small force to produce.

Screws are much used in presses of all kinds: as for squeezing oil and juices from the different kinds and parts of vegetables which contain them—linseed, rapeseed, almonds, apples, grapes, sugar-cane, &c. &c.;—in the cotton press, which reduces a great spongy bale, of which a few, comparatively, would fill a ship, to a compact package, heavy enough to sink in water;—a screw presses the paper against the types in the common printing press;—it is the great agent, also, in the coining machinery at our mints—and in letter-copying machines;—it is a screw which draws the iron jaws of a smith's vice together.

And as a screw can easily be made with a hundred turns of its thread in the space of an inch, and at perfectly equal distances from each other, it enables the mathematical instrument-maker to mark divisions on his work, with a minuteness and accuracy quite extraordinary. For suppose such a screw to be pulling a plate of metal forward, over which there is a steel marker with a very sharp point, that moves up and down quite perpendicularly, this may be let down once for every turn of the screw, and would make just as many marks on the plate as there were threads on the screw;

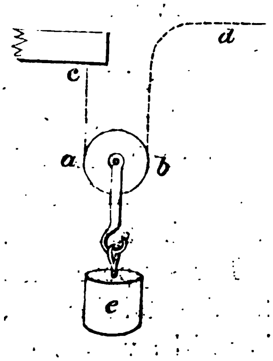
but it may be made to mark at every hundredth or thousandth of a turn of the screw, and will do it with equal accuracy. Such a machine is made to draw a hundred thousand lines in one inch.

The micrometers, by which the sizes of the heavenly bodies and of microscopic objects are ascertained, are moved by screws.

A *perpetual screw* is where a screw acts on the teeth of a wheel, so as to turn the wheel round.

The screw is an exceedingly useful contrivance; yet the friction is very great, and consumes a good deal of the force used.

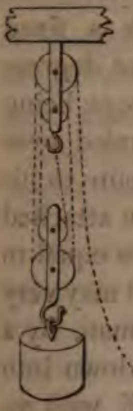
A common cork-screw is the thread of a screw without the spindle, and is used, not to connect opposing forces, but merely to enter and fix itself in the cork. There are complicated cork-screws now made, some of which draw the cork by the action of the screw, and others by a toothed rod and a wheel or pinion.

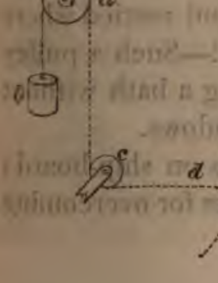


“ *The pulley* ” is another *simple machine*, by which forces of different intensities may be balanced. A simple pulley consists of a wheel as *a b*, which rests with its grooved circumference or edge on the bend of a rope, as *c a b d*, and to the axis of which the weight or resistance is attached, as at *e*.

In such a construction, it is evident that the weight, (let it be supposed ten pounds,) is equally supported by each end of the rope, and a man pulling at one end, only bears half of it, or five pounds; but to raise the weight one foot, he must draw up two feet of rope; that is, with the pulley he lifts five pounds two feet, instead of lifting ten pounds one foot without the pulley.

Many wheels may be combined together, and in many ways, to form compound pullies. Whenever there is but one rope running through the whole, as shewn here, the relation of power and resistance is known by the number of folds of the rope which support the weight. Here there are four folds, and a power of one hundred pounds would balance a resistance of four hundred. To persons using pullies, it is generally more convenient to stand upon the ground than to go up and apply their force directly to one of the supporting ropes; hence the last supporting rope generally passes over a wheel above, and comes down apart from the others, as seen here. As this portion is not directly connected with the weight, it adds nothing to the power of the pulley.





In *fixed pulleys*, like those shewn at *a* and *c*, there is no mechanical advantage, for the weight just moves as fast as the power; yet such pullies are of great use in changing the direction of forces. A sailor, without moving from the deck of his ship, by means of such a pulley, may hoist the sail or the signal-flag with great celerity to the top of the loftiest mast. And in the building of lofty edifices, where heavy loads of material are to be sent up every few minutes, a horse, trotting away with the rope from *d*, in a level court-yard, causes the charged basket *b* to ascend to the summit of the building more easily than if he had the power of climbing the perpendicular wall with it.

There is a case, however, in which a fixed pulley may become a balancer of different degrees of force; and it is where one end of a rope being fixed to a man's body, the other is carried over a pulley above, and brought down again to his hands: for safety this end also should be attached to his body. By pulling then with force equal to half his weight, he supports himself, and may very easily raise himself to the pulley. A man, by a pulley thus attached, may let himself down into a deep well, or from the brow of a cliff, with assurance of being able easily to return, although no one be there to help him; and cases have often occurred where a fellow-creature's life might have been saved, or other important object attained, by such means. How easily, by such a means, might persons ascend to or escape from the elevated windows of a house on fire! and how easily might the pulley be found and carried where ladders were not to be obtained!—Such a pulley furnishes an easy means of taking a bath without assistance, from a ship's stern windows.

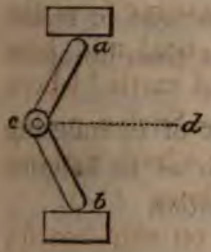
The chief use of the pulley is on ship-board; it is there called a block. It serves for overcoming the heavy strains of raising the anchor, hoisting the sails and masts, &c., and by means of it fewer sailors are rendered equal to the duties of the ship. But it is also used on shore, instead of cranes and capstans, for lifting weights, and overcoming other resistances.

Surgeons, in former days, when they trusted rather to force than to the address which better information gives, used pullies much to help in the reduction of luxations, and often without understanding the force of the pulley. A man who should now ignorantly stretch his patient on the rack, would be well requited by similar treatment.

The cranks of common bell-wires, in the corners of our rooms, are equivalent to fixed pullies.

It is difficult to assign a reason why the appellation of mechanical power should have been confined to the six contrivances now explained, for the following ones equally deserve it, and, as will be seen under hydrostatics and pneumatics, the most powerful engines of the kind do not belong to solids at all.

Engine of oblique action, is a name that may include a considerable variety of contrivances which connect different velocities.

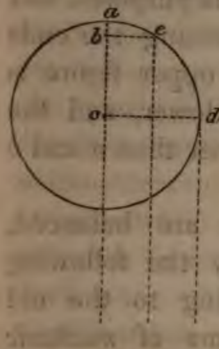


Suppose *c a* and *c b* to represent two strong rods, connected together by a hinge or joint at *c*, like a carpenter's ruler. If the distant ends be made to bear against two obstacles, at *a* and *b*, and then, by force applied to *c*, the joint *c* be straightened or carried towards *d*, the joint *c* will move through a much greater space than the simultaneous increase of distance between *a* and *b*; and, in proportion to this disparity, the power applied at *c* may be less intense than the resistances to be overcome at the extremities. The mechanical power of this contrivance increases rapidly, the nearer the jointed rods are to being straight.

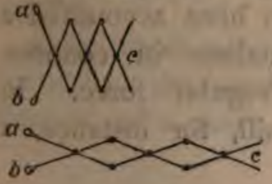
If we suppose the end *a* to be steadied by a hinge on frame-work, and the end *b* to bear upon that part of a printing-press which carries the paper against the types, we have represented a simple and excellent press, called the Russel press. A man's force at *d* becomes equivalent to a pressure of many tons, at the moment when the rods are drawn nearly to a straight line. This form is now preferred by some to the screw-press, as being simpler and cheaper.

For the same reason, that by urging *c* towards *d*, in the last figure, the extremities *a* and *b* are separated with great power, so by urging *c* in the contrary direction, the extremities would be drawn together with equal power: and if we suppose *a c b* to be a rope, to one end of which beyond a block at *a*, great resistance is attached, one man, by pulling at *c*, may move such weight or resistance, although many times greater than he could move by his direct power.

The following is another mode of connecting an oblique and a direct force, so as to balance them, although of different intensities.



If to turn a wheel *a e d*, a weight be suspended from *d*, it is acting directly, for it descends just as fast as the circumference of the wheel moves, and would therefore be acting with its whole strength: but if it were suspended from the point *e*, it would be acting obliquely, and would not descend so fast as a weight at *d*, and would have as much less effect on the wheel than such weight as the line *e b* is less than the line *d c*. The reason of this will be understood by referring to the subject of *resolution of forces*, in a former part of the work. And for the same reason, if such a wheel were used for lifting weights, a man could lift as much more with it at the point *e* than he could at the point *d*, as the line *d e* is longer than *e b*. A man turning this wheel in the direction from *e* to *a*, with a weight hanging at *e*, would be lifting the weight exactly as if he were rolling it up the inclined plane or curve *e a*, instead of lifting directly from *b* to *a*. This figure is useful also in explaining the varying intensity of the action of a crank or winch, and of the combination of levers used in the *Stanhope printing press*, the strength and support afforded by oblique stays and rafters in buildings and in ships' rigging, and many other kindred matters.



The arrangement of cross-jointed wires, represented here, connects different velocities, and therefore is really a mechanic power.

It has been applied to some curious purposes, but to none of much utility. By pressing the ends *a* and *b* towards each other, the upper figure is immediately converted into the lower, and the end *c* darts outwards much farther than *a* and *b* approximate.

Different intensities of force are balanced, although not simultaneously, by the following means, which therefore, according to the old idea, would also merit the name of *mechanic powers.*

A man may have something to effect, which a forcible push would accomplish: but not having the means of pushing directly with sufficient strength, he may employ a certain time in carrying a weight to such an elevation above his work, as that when it is let fall, it may do what is required. Here the continued effort of the man in lifting the weight, to a height of perhaps thirty feet, may be just sufficient to produce a blow which will cause a stake or pile to sink into the earth one inch; and the contrivance has therefore balanced forces, which are to each other in intensity as thirty feet to an inch.

Hence also, hammers, clubs, battering rams, —are all machines which enable a continued moderate effort, to overcome a momentary great resistance. The sling belongs to the same class.

The fly wheel, which by persons ignorant of natural philosophy has often been accounted a positive power, merely equalizes in common cases the effect of an irregular force. In using a winch to turn a mill, for instance, a man does not act with equal force all round the circle, but a heavy wheel attached to the axis receives momentum, while his action is above par, and gives it again while it is below par, and thus equalizes the movement. And in every circular motion produced by a crank, as in moving a turning lathe or grindstone or spinning-wheel with the foot, the force is only applied during a small part of the revolution, or in the form of interrupted pushes, yet the motion goes on steadily, because the grindstone or wheel or lathe becomes a fly and reservoir, equalizing the effect of the force. In the steam engine which moves machinery by a crank, the push up and the push down of the piston, by means of a heavy fly, are converted into a very steady rotatory motion.

A heavy wheel has sometimes been used as a concentrator of force and a mechanic power. By means of a winch or a weight or otherwise, motion or momentum is gradually increased and accumulated in the wheel, and is then made to expend itself in some instantaneous and proportionally great effect.

Thus a man lifts a very heavy weight, by having a fly wheel over it. He first gives motion to the wheel by turning a winch for a certain number of seconds, and then hooks a rope from the weight to its axle; the wheel, continuing to turn, winds this rope round its axle, and lifts the heavy weight.

A fly wheel moved in the same manner, and containing the result of perhaps one hundred seconds, of a man's action, is made to impel a screw and with one blow or punch to stamp a perfect medal, or to form a spoon from a rough flat plate of silver.

A spring in the same way may become a mechanical power. A man may expend some minutes in bending a strong one, which is afterwards to exert its energy in an instantaneous blow. A gunlock shews this on a small scale. The slow bending of a bow, which is afterwards to throw the arrow with such velocity, is another instance.

These are the means of balancing forces of different intensities, which the solid state of bodies affords us. We shall find other mechanic powers belonging to liquids and airs. They are all of inestimable value to man, by enabling him to accommodate the forces which he can command to any kind of work which he has to perform. Thus his millstone is made to turn with the same velocity, whether it be moved by the slow exertion of a horse or bullock walking in a ring, or by the quicker motion of the river gliding under the wheel, or by the rapid gush and cascade from the mill-dam, or even by the invisible swiftness of the wind. And again, each of these forces may be applied to turn the heavy millstone or to twist a cotton thread.

The wants of men seem first to have led them to use the simple machines for the purposes of raising great weights, or overcoming great resistances, and hence they were long called the mechanic powers, particularly the lever, wheel and axle, plane, wedge, screw, and pulley: but the term conveys to the uninformed, a false idea of their real nature, and has begotten the common prejudice with respect to them, that they save labour. Now so far is this notion from being true, that in using these machines to help in any case, there is even more labour or bodily exertion expended than there would be without them; for in addition to the work to be done, the friction of the machine must be overcome.

One man may be able, with a tackle of pullies having ten plies of the rope, to raise a weight which it would require ten men to raise at once without pullies. But if the weight is to be raised a yard, the ten men will raise it, by pulling at a single rope and walking one yard, while the single man at his tackle must walk until he has shortened the ten plies of rope of one yard each; that is, he must walk ten yards, or ten times as far as the ten men did. In both cases, therefore, we have just the same quantity of man's work used, to accomplish the same end, in the one case performed by ten men in one minute, in the other by one man in ten minutes; and if the work continues longer, let us say a whole day for the ten men, it will last ten days for the single man, and there will be just ten days' wages of a man to pay in both cases: there is, therefore, no saving of labour from using the pullies, but a loss, because of the friction. Now exactly the same is true of all other machines; none of them save labour, but they allow a small force to take its time to produce any requisite magnitude of effect.

The real advantages then of these machines are such as the following:

That a man's effort, or any single power which is always at command, by working proportionally longer, will answer the purpose of the sudden effort of many men, even of hundreds or thousands, whom it might be most inconvenient and expensive, or even impossible, to bring together.

A small ship's company weighs the anchor by means of the capstan.

A solitary workman, with his screw or other engine, can press a sheet of paper against the types, so as to take off a clear impression; yet to do this, without the press, the push of fifty men would be insufficient; and these fifty men would be idle and superfluous except just at the instants of pressing, which recur only now and then. In this way the screw may be said to do the work of fifty men, for it is as useful here.

A man with a crow-bar may move a great log of wood to a convenient place in the manufactory, which it would have required twenty men to move without the crow-bar; and although the single man takes twenty minutes perhaps to do what the many men would have done in one minute, as the twenty might not have been wanted again for the rest of the day, the crow-bar is really here nearly as useful as twenty men.

It is so important to have correct notions on the subject of the simple machines or mechanical powers, that more time has been allotted to it than to some may seem due. After the examination which it has now undergone, the author hopes that none of his readers would have difficulty in exposing immediately any fallacy connected with it;—of supposing, for instance, that a great pendulum, or a spring-plank, or a heavy wheel, &c. can ever exert more force than has passed into it from some source of motion.

> "*By solid connecting parts, also, the direction of any existing motion or force may be changed. Hence the endless variety of* COMPLICATED MACHINES." (*Read the analysis at page* 107.)

It is this power of changing the direction of motion, joined with the power of adjusting intensities of force by the simple machines last described, which has enabled man to make complicated machines, almost rivalling in their performance the work of human hands. It would be endless to attempt the enumeration of all the modes in which the direction of motions may thus be changed, for it would be to enumerate and describe the whole apparatus of the arts and sciences, but we shall advert to a few as specimens.

Straight motion into rotatory.—The straight motion of wind or water becomes rotatory in wind or water-wheels.—The straight-downward pressure of the human foot, acting at intervals on a treadle and crank, turns round the grindstone, and turner's lathe, and spinning-wheel.—The alternate rising and falling of a steam-engine piston, also by a crank, turns the great fly-wheel and prime axle of motion.

Rotatory motion into straight.—An axle in turning winds up a rope, and lifts a weight in a straight line.—A crank on a turning axle, being fixed to a pump-rod, works the pump up and down, or works a saw.—Pallets or teeth on a turning-wheel act on the handle of a great forge hammer, and every tooth produces a blow.

We need not multiply instances. By a visit to the great manufacturing towns, or, indeed, by simply directing the eyes to what is passing around, in any part of the civilized world, we discover miracles of mechanic art. We see machines driven by wind and water for grinding corn;—machines for sawing wood and giving it various forms;—machines in which rods of metal are seized between great rollers, and are flattened at once into thin plates, as readily as if they were of clay;—machines for slitting these plates into bars or ribbons;—spinning machines, which perform their useful office even more uniformly than human hands could do, and form thousands of threads at once through the operation of a single steam engine;—weaving machines, which accomplish even their difficult task with singular perfection;—paper machinery, which takes worn out and apparently useless remnants of our apparel, and converts them into the uniform and beautiful texture of paper, a texture that, with the assistance of the pen, or types, or engraved plate, becomes a magic conservatory of mind, shutting up among its folds the brightest effusions of genius, and ready at every instant to disclose them to the inquiring student, nothing changed after thousands of years;—coining machinery, which divides and stamps thousands of beautiful medals in an hour, and keeps an exact record of its work;—cranes,—pile engines,—turning lathes,—time-pieces,—all the implements of agriculture, of mining, of navigation, &c. &c. If Aristotle deemed the title or definition of *tool-using animal* the proper one for man two thousand years ago, what title should be given now?

In many of the complicated machines, several of the simple ones are found as elements; and in the same machine may be comprized many of the means of changing the direction of motion.

" *Friction.*" (*Read the analysis, page* 107.)

In estimating the effects of all these mechanical contrivances, according to the rule laid down of the comparative velocities of the power and resistance, there is an important correction to be made, on account of the friction or rubbing of the moving parts on each other. In the steam engine, where the rubbing parts are numerous, the loss of power from friction amounts to one-third of the whole.

Impediment from friction seems to be owing to two causes: 1st, to a degree of cohesion between the touching substances; 2d, to the real roughness of the rubbing surfaces, how smooth soever they may appear to the naked eye.

And it is supposed to be, because in pieces of the same substance the roughnesses, or little projections and cavities, mutually fit each other, as the teeth of similar saws would, that the friction is greater between such, than between different substances, which being of dissimilar grain, may be supposed not to fit or touch so completely.

The friction of a piece of iron, wood, brick, stone, &c. rubbing on another piece of the same substance, has been measured by laying it upon an inclined plane of that substance, and gradually lifting one end of the plane, until the lump began to slide,—the inclination of the plane, just before the sliding, is called the angle of repose.

It is this angle in the different substances concerned, which determines the form of hills of sand, gravel, earth, &c. of the sides of canals, the banks of rivers, &c.

And if the thread of a screw winds round the spindle with a less angle than this, the screw can never slip or slide by force acting against its point.

But for friction, a man in walking on the ground or pavement would always be as if walking on ice; and our rivers, that now flow so calmly, would all be frightful torrents.

When it is an object to diminish friction between rubbing surfaces, the following means are used, either singly or in combination according to circumstances.

1. Making the rubbing surfaces smooth, but within certain limits, for, when too smooth, they approach so near that a degree of cohesion takes place.

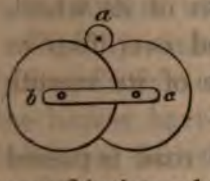
2. Using substances of different nature to rub on each other: axles are made of steel, for instance, and the parts on which they bear are made of brass; in small machines, as time-keepers, the

steel axles often turn in agate or diamond. The swiftness of a skaiter depends much on the great dissimilarity between steel and ice: and it illustrates the same law.

3. Interposing some substance between the rubbing parts, as oils for metals; soap, grease, black-lead, &c. for wood.

4. Diminishing the touching surfaces, as in making a small axis to a wheel.

5. Using wheels, as in wheel carriages, instead of dragging a load along the ground. Castors on household furniture are miniature wheels.



6. Using what are called friction wheels: these still farther diminish the friction even of a smooth axis, by allowing it to rest on their circumferences, which turn with it. *a* represents the end of an axis, and *b* and *c* two friction wheels, on which it rests.

7. Placing the thing to be moved on rollers or balls, as when a log of wood is drawn along upon rounded pieces of wood as rollers; or when a cannon, with a circular base to its carriage, turns round by rolling on cannon balls laid on a hard level circular bed. In these two cases there is hardly any friction, and the resistance is merely from the obstacles which the rollers may have to pass over.

Of all rubbing parts the joints of animals are those which have the least friction, considering the strength, frequency, and rapidity of their movements. We study and admire the perfection found in them, without being able very closely to imitate it.

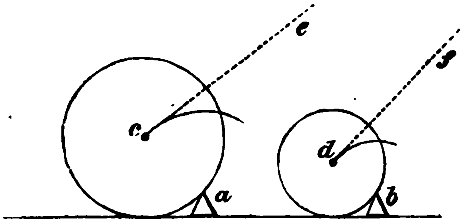
Wheel carriages illustrate many of the circumstances connected with friction, and moreover possess qualities which all may find it useful to know, as appertaining to the most common of our machines.

Wheel carriages have three advantages over the sledges, for which they are the substitutes:

1. The rubbing, instead of being between an iron shoe and every stone and irregularity on the road, is between the axle and its bush, which have surfaces smoothed and fitted to each other, and well lubricated.

2. While the carriage has moved forward, perhaps fifteen feet, by one revolution of its wheel, the axle has only rubbed or passed over four or six inches of the internal surface of its smooth greased bush.

3. Any abrupt obstacle on the road is passed over by the wheel, so as to cause the axle to describe a gently rising slope or curve, as shewn in the figure where *a* represents an obstacle on the road, and the curve at *c* is the path of the axle in surmounting it. Here the wheel seems to be rising upon an inclined plane, and giving the drawing animal the relief which such a plane brings. This advantage is always proportioned to the greater size of the wheel, for the smallest wheel *d* rises in the steeper curve from *d*, to surmount



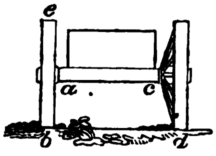
the same size of obstacle. The two curves from *c* and *d* shew the true paths of the axles of the carriage, and the two lines *c e* and *d f* shew the directions of their commencements.

From these three causes, the difference in performing the same journey of a mile, by a sledge and by a wheel carriage would be, that while the first rubbed over every roughness found in the mile, and were jolted by every irregularity, the rubbing part of the latter, the axle, would very slowly slide over only twenty or thirty yards of a smooth oiled surface, in a gently waving line. It is ascertained that the resistance is thus reduced to 1-100th of what it would be in a sledge.

On hilly roads, in descending, it is common to *lock* or fix one of the wheels; yet it is seen that the horses have then to pull as much, as on a level road with the wheel free; shewing the effect of a little increase of friction.

The application of springs to carriages, which is an improvement of comparatively recent date, not only renders them soft vehicles on rough roads, but much lessens the pull to the horses. When there is no spring, the whole load must rise with every rising of the road, and must sink with every depression, and the depression costs as much as the rising, because the wheel must be drawn up again from the bottom of it; but in a spring carriage moving rapidly along, only the parts below the springs are moved in correspondence with the irregularities of the road, while all above, by the inertia of the matter have a soft and steady advance. Hence the superiority of those very modern carriages, furnished with what are called *under springs*, which insulate from the effect of shocks, all the parts, excepting only the wheels and axle-trees themselves. When only the body of the carriage is on springs, as was the fashion until lately, the horses have still to rattle the heavy frame-work below over all irregularities, and the wheels require to be of much greater strength to bear the consequent shocks.

The wheel of a carriage, simple as it appears to us now, from our extreme familiarity with it, is a thing of very nice workmanship, and which has exercised much ingenuity. It acquires astonishing strength, indeed that of the arch, from what is called its dished form, seen in the wheel *c* as contrasted with *a*; and that form is farther useful in this, that when the carriage is on an inclined road, and more of the weight therefore falls upon the wheel on the lower side, the under spokes of that wheel become nearly perpendicular, and thereby support the increased weight more safely.



The subject of wheel carriages is interesting to medical men, because it often occurs to them to have to direct in transporting the sick or wounded. And many a medical man practising in an extensive district, or in a large town, is indebted to a well-constructed carriage for two or three valuable hours in every day employed in reading or writing, as he is carried from place to place.

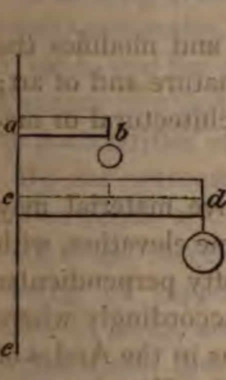
It is perhaps difficult to conceive any thing more elegant and perfect in all parts, than the carriages of modern refinement; and it is no wonder that a man, who contrasts them gliding swiftly along the prepared levels and slopes of our modern landscapes, with the awkward vehicles and bad roads of former times, should imagine that absolute perfection had at last been attained. Yet, we are perhaps now on the eve of a farther change, which for general purposes will be of much greater importance than all that has as yet been achieved,—*viz.* by the general adoption of rail-roads, and of carriages to suit them. It has long been known that it costs more force to drag a loaded waggon up one inconsiderable hill, than to send it thirty or forty miles along a level rail-road, but until lately this knowledge has scarcely been acted upon. To persons conversant with political economy, it would be quite superfluous to speak of the advantages of any greater facility of intercourse, but to those who are not, the following reflections may be interesting.

In reviewing the history of the human race, we find every remarkable increase in civilization to have taken place very much in proportion to the facilities of intercourse enjoyed in particular situations: first, therefore, civilization grew along the banks of great rivers, as the Nile, the Euphrates, and the Ganges; or along the shores of inland seas and archipelagos, as in the Mediterranean and the numerous islands of Greece; or over fertile and extended plains, as in many parts of India. The reason is obvious. When the situation thus binds a number of individuals into one body, the useful thought or action of any one unusually gifted, and which in the insulated state would soon be forgotten and lost, extends its influence immediately to the whole body, and becomes the thought or action of every one under the same circumstances: it is recorded for ever, as part of the growing science or art of the community. And in a numerous society, such useful thoughts and acts are more frequent, because an emulation arises in all the pursuits that can contribute to the well-being of the society, from each individual feeling that he has the eyes of a multitude upon him, and that the rewards of excellence will be proportionally great. Men soon learn to estimate aright these and many other advantages of easy intercourse: and after having seized with avidity all the stations peculiarly fitted by nature for their purposes, they begin to make new stations themselves, and to improve upon the old: they create rivers and shores and plains of their own, that is, they construct canals and basins and roads, and thus connect districts which nature seemed to have separated for ever. In the British isles, whose favoured children have so proudly taken the lead in shewing the prodigies which wise policy may effect, the advantages arising from certain lines of canal and road first executed, soon led to numberless similar enterprizes, and within half a century the empire has become intersected in all directions: but it seems as if the noble work were yet to be crowned by what will eclipse all that has yet been done, viz. by the substitution above-mentioned of level rail-roads for many of the common roads and canals. Several rail-ways of considerable extent have already been established, and although they and the carriages upon them are far from having the perfection which philosophy says they will easily admit, the results have been most satisfactory. If we suppose the price of transporting things and persons from place to place reduced by them to a fourth of the present charge—and in many cases it will be much less—and if we suppose the time of journeying with safety, reduced in some corresponding degree, and of this there is as little doubt—the general introduction of such means of transport would effect a greater revolution and improvement in the state of society, than perhaps any other single circumstance that can be mentioned. Without in reality changing the distances of places, it would have the effect of bringing all parts nearer to each other, and would give to the whole kingdom the conveniencies of both town and country. In any one part, a man might consider himself as very near to any other part, for at the expense of as little time and money as he now spends to go a short distance, he might go a long one. The over-crowded and unhealthy parts of towns would immediately scatter their inhabitants to the country; for a man, with such cheap and speedy conveyance at his command, would be as near his business, although living several miles off, as he is now in an adjoining street. A man living in the remote mountains might consider the ocean as only beyond the nearest hill, for he would only have to wish it, and he would be there. In like manner, the inhabitant of the coast, for a very small sacrifice, might visit the counties of the interior. The present heavy charges for bringing produce to market from great distances being thus nearly saved, the buyer every where would purchase cheaper, and the producer would still be better remunerated. In a word, such a change would arise as if the whole of Britain had been compressed by magic into a circle of a few miles in diameter, yet without any single part losing the least of its magnitude or beauties; and the sea would be but a little way south of the metropolis, and Edinburgh but a little way north, and the mountains of Wales but a little way to the west. This appears visionary: but it is less so than it would have been, seventy years ago, to anticipate what has now come to pass, that the common time of travelling from London to Edinburgh would be forty-six hours. At the opening of the rail-road near Darlington last year, a train of loaded carriages was dragged along by one little steam engine, a distance of twenty-five miles within two hours: in some parts of the journey the speed was more than twenty miles an hour. The whole load was nearly equal to a regiment of soldiers, and the coal expended was under the value of a crown. An Island with such roads would be an impregnable fortress; for in less time than an enemy would require to disembark on any part of the coast, the forces of the country might be concentrated to defend it.

"*Strength depends on magnitude, form, and position, as well as on the natural cohesion in the material.*" (*Read the analysis, page* 107.)

The details connected with this branch of the subject belong to the practical engineer, but there are some general truths that should be familiar to every body.

1*st. Of similar bodies the largest is proportionally the weakest.*



Suppose two blocks of stone left projecting from a rock that has been hewn, of which blocks one, as *d*, is twice as long and deep and broad as the other *b*. The larger one *d*, will by no means bear as much more weight attached to its end than the small one, as it is larger, and for two reasons. 1st. In the longer block, any portion of the surface of attachment at *c*, in bearing the block itself, has to support twice the extent of projection that any equal surface of attachment has to support in the shorter block at *a*; and 2dly, both the additional substance, and any thing appended at the outer extremity of the larger block, are acting with a double lever advantage to break it, or to destroy the cohesion at *c*. Hence it is that if any such projection be carried out very far, it breaks off or falls by its own weight alone. We may consider each particle in the surface at which the block and rock join, to be supporting by its cohesion all the particles directly outside of it or beyond it; and of course as the length of the block is increased, each particle at the junction has more to do, and at last more than it can do. That a large body therefore, may have proportionate strength to a smaller, it must be made still thicker and more clumsy than it is longer; and beyond a certain limit no proportions whatever will keep it together, in opposition to the force of its own weight.

This great truth limits the size and modifies the shape of most productions of nature and of art; —of hills, trees, animals, architectural or mechanical structures.

Hills. Very strong or cohesive material may receive the form of hills of sublime elevation, with very projecting cliffs and very lofty perpendicular precipices; and such are seen accordingly where the hard granite is the material, as in the Andes of America, the Alps of Europe, the Himalayas of Asia, and the Mountains of the Moon in Central Africa. But rocks of inferior strength can neither support much perpendicular elevation, nor much projection of cliff.

Even in granite, which is the strongest of rocks, there is a limit to these particulars; and if any elevation or cliff more remarkable than now remains on earth, were by any chance to be produced again, the law which we are considering would prune the monstrosity. The grotesque figures of rocks and mountains seen in the paintings of the Chinese, and expressing their notions of perfect sublimity and beauty, are caricatures of nature, which never could exist in reality. Some of the smaller islands in the Eastern Ocean, however, and some of the mountains of the chain visible along the coasts of Borneo and Palawan, in the voyage towards China, exhibit perhaps the very limits of possibility in singular shapes, and are so extraordinary as to give a pretext for the exaggeration.

A striking gradation of form is observable from granite mountains, down to those of chalk or gravel or sand, and the geologist can generally tell the substance of which a hill is composed, by observing the peculiarities of its shape.

By the unceasing action of winds, and rain, and currents, and frost, upon the mineral masses around us, there is a frequent undermining and wasting of supports, and every now and then immense rocks, and almost hills, are torn from the station which they have held ever since the earth received its present form, and fall in obedience to the law now explained.

The size of vegetables of course is obedient to the same law, and hence we have no trees reaching a height of three hundred feet, even when perfectly perpendicular, and in the forests which have been unmolested from the beginning of time. And oblique or horizontal branches are kept within very narrow limits, by the strength required to support them. What a difference is there between the delicate and slender proportions of a young oak or elm, or beech, while yet in the nursery, and its sturdy form when it has stood for centuries, and has become the monarch of the park or forest.

Animals furnish other interesting illustrations of this law.

How massive and clumsy are the limbs of the elephant, the rhinoceros, the heavy ox, compared with the slender forms of the stag, antelope, and greyhound! And unless the bones were made of stronger material than now, an animal much larger than the elephant would fall to pieces from internal weakness. Many have doubted whether the mammoth, or antediluvian elephant, could have lived on dry land, or whether he must have been amphibious, that his great body might be generally borne up by water. The whale is the largest of animals, but it feels not its mighty weight, from its lying constantly in the liquid support of the ocean.

The giants of the heathen mythology could not have existed upon this earth, for the reason which we are now considering. On our moon such creatures might be, because there gravity is so much less, on account of her smaller size: and in the planet Jupiter, which is many times larger than the earth, an ordinary man from hence would be carrying in the simple weight of his body, a load sufficient to crush and break the legs which supported him. The phrase, a *little compact man,* expresses the fact that such a one is stronger in proportion to his size than a taller man.

The same law limits the size or height of *houses.*

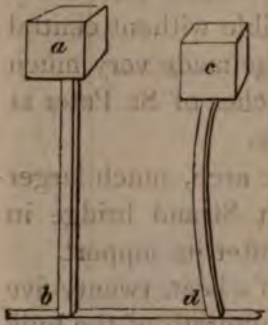
In those of fourteen stories, lately burned under the castle of Edinburgh, there was danger of the superincumbent wall crushing the foundation.

Roofs. Westminster Hall, in London, nearly reaches the limit of width possible without central supports; and no dome could be made very much larger than those of the churches of St. Peter at Rome, and St. Paul in London.

Arches of a bridge. A stone arch, much larger than those of the magnificent Strand bridge in London, would crush and splinter its support.

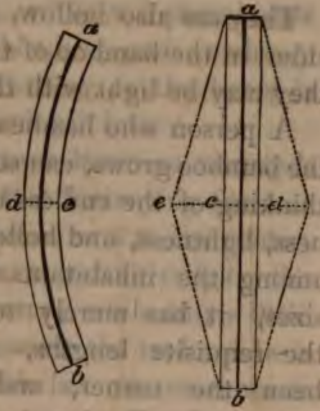
Ships. The ribs or timbers of a boat, twenty-five feet long, have scarcely one-hundreth of the bulk of those of a ship two hundred and fifty feet long. A ship's yard of ninety feet contains perhaps twenty times as much wood as a yard of thirty feet, and even then is not so strong in proportion. And if ten men may do the work of a three-hundred-ton ship, many more than three times that number will be required to man a ship three times as large. Very large ships, such as the two lately built in Canada, of nearly ten thousand tons each, are weak from their size alone, and the loss of these two first specimens will hardly encourage to the building of others like them.

The strength of structures, as connected with the form and disposition of their parts, will be understood by considering the two cases of *longitudinal* and *transverse* compression; and it will be found to depend on causing the force which tends to destroy, to act equally on the whole resisting mass, and with as little mechanical advantage as possible.



In longitudinal compression, as produced by the body *a*, on the atoms of the support *b*, the weight can only destroy the support, by crushing it in opposition to the repulsion and impenetrability of the atoms; and crushing is the most difficult mode of breaking. Hence a very small pillar, if kept perfectly straight, will support a very great weight; but if the pillar begins to bend, or if it was crooked originally, it resists with only part of its strength. The reason is, that by the bending of the pillar, as in *c d*, the whole weight above is immediately supported on the atoms of the concave side only, which, therefore, are in double danger of being overpressed and crushed, while those on the convex side, separated from their natural helpmates, are in the opposite danger of being torn asunder.

Long pillars or supports are weaker than short ones, because they are more easily bent; and they are more easily bent because a very little and easily effected yielding between each two of many atoms makes a considerable bend: while in a very short line or pillar there can be no bending without a great change in the relation of the individual atoms, and this cannot be effected without great force. In a long pillar the weight or bending force, acts nearly with the mechanical advantage of a lever half the length of *a b*, against the strength resisting at a lever only half the breadth of *d c*; while in a short pillar, the strength resists by a lever nearly as long as that of the weight. Any stay or projection, as *a e b*, which prevents bending thus, really increases the strength of a pillar.



A column with ridges projecting from it, is stronger than one that is perfectly smooth.

A hollow tube of tinned iron or copper is stronger than the same quantity of metal as a solid wire.

Cast-iron pillars are generally made hollow, that they may have strength with as little metal as possible.

In the most perfect weighing-beams for delicate purposes, that there may be as little weight as possible with the required strength, the arms, instead of being solid metal, are formed into hollow cones, and the metal is not much thicker than paper.

Masts and yards for ships have been made hollow to obtain lightness with strength.

In Nature's works we have to admire many illustrations of the same kind.

The stems of many vegetables, are ribbed or angular and fluted, instead of round, that they may have strength.

They are also hollow, as in corn-stalks, in the elder, in the bamboo of tropical climates, &c. that they may be light with their strength.

A person who has been in the countries where the bamboo grows, can scarcely mention it without thinking of the endless uses to which its straightness, lightness, and hollowness make it applicable among the inhabitants. As it is found of all sizes, it has merely to be cut into pieces of the requisite lengths, and Nature has already been the turner, and the polisher and the borer, &c. Bamboo is the chief material of their dwellings, and of their curious chairs, couches, beds, &c. Their flutes and other wind instruments are the bamboo with holes bored at the requisite distances; conduits for water are pipes of bamboo; bottles and casks for preserving liquids are single joints of larger bamboo, cut off with their partitions remaining; and bamboo split into threads is twisted into rope, &c. &c.

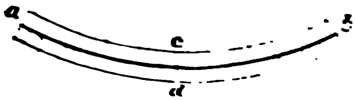
The hollow stiffness of the quills of birds is another illustration of this class: also

The hollow bones of birds: and

The long bones of animals, generally, which are strong and hard externally, with loose texture and narrow cells within.

Transverse Pressure.

When a beam is supported at its extremities, as at *a* and *b*, it bends down in the middle by its weight, and the particles on the



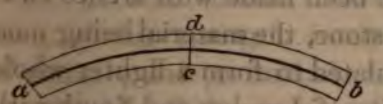
upper side are compressed, while the parts below are distended; and the bending and tendency to break are greater, according as the beam is longer and its thickness or depth less.

The tendency to break in a beam so situated, is known by considering the destroying force as acting by the long lever from *a* or *b* to the centre, and the resisting strength as acting only by the short lever from *d* to the centre; while only a little of the substance of the beam on the under side is allowed to resist at all. This last circumstance is so remarkable, that the scratch of a pin on the under side of a plank resting on its ends, will sometimes suffice to begin the fracture.

Because the resisting lever is small in proportion as the beam is thinner, a plank bends and breaks sooner than a beam, and a beam resting on its edge bears more than if resting on its side. Where a single plank or beam cannot be found deep enough to have the strength required, several are joined together, and in a great variety of ways, as is seen in house-rafters, &c.

The arched form bears transverse pressure so admirably, because it allows the pressure to act only so as to compress all the atoms or parts at once, and in the same degree.

By comparing this figure with the last, we see at once that here the atoms on the under side must be compressed, as well as those on the upper, and cannot therefore be torn, or overcome separately. The whole resists



like a perfectly straight pillar under a weight, and is just as strong.

To adapt the curve to the size of the arch and to the nature of the material, requires a perfect acquaintance with measures, &c.

An error, which has several times been committed by bridge-builders, is neglecting to consider the effect of the horizontal thrust of the arch on the piers. Each arch is an engine of oblique force (see page 161), pushing the pier away from it. In one instance, an arch of a bridge fell, and immediately the adjoining piers were pushed down towards it by the thrust, no longer balanced, of the arches beyond them ; and the other arches followed like those of a bridge built of cards, when the first is pulled down.

It is not known at what time the arch was invented, but it was in comparatively modern times. The hint may have been taken from nature, for there are some instances in alpine countries of natural stone arches, where rocks have fallen between rocks, and have there been arrested and suspended. Nothing can surpass the strength and beauty of some modern stone bridges ; such as that from the Strand in London, of nine arches, all of granite, and each stretching one hundred and fifty feet.

Iron bridges have been made with arches twice as large as those of stone, the material being more tenacious, and calculated to form a lighter whole. That between the city of London and Southwark, of three fine arches, is a noble specimen, and compared with the bridges of half a century ago it appears almost a fairy structure of lightness and grace.

The great domes of churches, as those of St. Peter's in Rome and St. Paul's in London, have strength on the same principle as simple arches. They require to be strongly bound round with chains and iron bars at the bottom, to counteract the horizontal thrust of the superstructure.

The Gothic arch is a pointed arch, and calculated to bear the chief weight on its summit or key-stone. Its use, therefore, is not properly to span rivers as a bridge, but to enter into the composition of varied pieces of architecture. With what effect it does this, is seen in the truly sublime Gothic structures which still adorn so many parts of Europe.

The following are other instances of strength from the arched form:—a thin watch-glass bears a very hard push;—a dished or arched wheel for a carriage is many times stronger to bear all kinds of shocks than a perfectly flat one;—a full cask falls with impunity, where a strong square box is dashed to pieces;—a very thin globular flask of glass may be corked and sent down many fathoms into the sea, and will resist the pressure of the water around it, while a square bottle, with sides of almost any thickness, is broken to pieces.

We have an animal illustration of the arched form, giving strength, in the cranium or skull of animals, and particularly in that of man. The brain required the most perfect security, and by the arched form of skull this has been given with little weight. The common egg-shell is another example: what hard blows of the spoon or knife are often required to penetrate this wonderful defence which has been provided for the yet dormant life!—how weak the same substance would be without the arched form we see in a scale from a piece of freestone, which so readily crumbles between the fingers.

The whole business of determining the best forms of beams and joists, for particular purposes, of arches, and domes, &c. is the business of strict calculation, and belongs therefore to the study of the measures.

It was a beautiful problem of this kind, which Mr. Smeaton, the English engineer, solved so perfectly, in the construction of the far-famed Eddystone lighthouse. He had to determine the form and dimensions of a building, which should stand firm on a sunken rock in the channel of a swift ocean tide, and exposed to the fury of tempests from every quarter. Only the man who has himself been driven before the irresistible storm in the darkness of night, and in the midst of dangers, and whose eyes have watched the steady ray from the lighthouse which saved him, can appreciate fully the importance of the studies which bring such useful results; and he feels how happy he is to have fellow men, whose talents, although exerted perhaps for individual good, are yet by God's providence made to accomplish the most philanthropic ends, and to bind the whole of human kind into one great society of helping brotherhood.

THE SECTION ON ANIMAL AND MEDICAL MECHANICS.

Mechanism of the Human Skeleton.

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Having now completed our study of general mechanics, with the light thence derived, we shall proceed to examine that most interesting illustration of many of the truths which have been explained—the solid frame of the human body—a perfect work of an unerring Engineer!

There is scarcely a part of the animal body, or an action which it performs, or an accident that can befal it, or a piece of professional assistance which can be given to it, that does not furnish illustration of some truth of natural philosophy; but were we here to enter into great detail, we should be giving minute lectures on anatomy, and physiology, and surgery, and medicine, instead of explaining general laws. We shall therefore only touch upon as many particulars as will make the understanding of all the others perfectly easy; taking care to include among our illustrations, those matters of importance which would be most likely to escape the notice of a hasty student.

The *cranium* or *skull* was already mentioned as an instance of the arched form answering the purpose of giving strength. The brain, in its nature, is so tender and susceptible of injury, that slight local pressure disturbs its action. Hence a solid covering like the skull was required, with those points made stronger and thicker which needed greater strength to repel probable injuries.

An architectural dome is constructed to resist one kind of force only, and in one direction, *viz.* gravity; and therefore its strength increases regularly towards the bottom, where the weight and horizontal thrust of the whole are to be resisted; but in the skull the case is very different: the tenacity of its substance is a hundred times more than sufficient to resist gravity, and is calculated to resist forces of other kinds and in all directions. When we reflect on the strength displayed by the chalky film of the egg-shell, owing to its arched form, we need not wonder at the severity of blows which the cranium can withstand.

In the early fetal state, that which afterwards becomes the strong bony case of the brain, exists only as a tough flexible membrane. Ossification commences in this membrane, long before birth, at a certain number of points and the portions of the skull formed around the different points soon acquire the appearance of so many scales or shells applied on the surface of the brain, and held together by the remaining membrane not yet ossified. During parturition, these portions or scales overlap at their edges, so as most usefully to diminish the size, and to change the form of the head. They afterwards become firmly fixed together, by projections of bone from each, shooting in among similar projections in the adjoining ones, until they all mutually cohere by perfect dove-tailed joints, like the work of a carpenter. These joints are called the sutures of the cranium, and are visible to extreme old age. During early childhood, the cranium is still to a certain degree yielding and elastic, and the falls and blows so frequent during the lessons of walking and acting are borne with impunity. The mature skull consists of two *layers* or *tables*, with a soft *diploe* between them; the outer table is very tough, and well calculated to resist blows, with its parts dove-tailed into each other as tough wood would be by human artificers: the inner table is harder and more brittle, and its edges merely lie in contact, because its brittleness would render dovetailing useless.

A very severe partial blow on the skull generally fractures and depresses the part, as a pistol-bullet would: while one less severe, but with more extended contact, being slowly resisted by the arched form, often injures the skull by what is synonimous with the *horizontal thrust* in a bridge, and causes a crack at a distance from the place struck, sometimes even on the opposite side.

Mr. C. Bell, in various parts of his works, has made remarks on the mechanism of the cranium, which well deserve attention.

In the lower jaw we have to remark the greater mechanical advantage, or lever power, with which the muscles act, than in most other parts of animals. The temporal and masseter muscles pull almost *directly*, or at right angles to the line of the jaw, while in most other cases, as in that of the deltoid muscle lifting the arm, the muscles act very *obliquely*, and with intensity diminished in proportion to the obliquity. An object placed between the back teeth is compressed with the whole direct power of the strong muscles of the jaw. Hence the human jaw can crush a body that resists with great force, and the jaws of the lion, tiger, shark, and crocodile, &c. are much stronger still.

The *teeth* rank high among those parts of the animal body, which appear almost as if they were the fruits of distinct miraculous agencies—so difficult is it to suppose a few simple laws of life capable of producing the variety and yet perfect adaptation of parts which they exhibit. They form an extraordinary set of chissels and wedges for cutting and tearing the food, so arranged as to be most efficient in their operations, and with an exterior enamel, so hard, that in early states of society, teeth were used where steel is now. It seems as if the laws of life, astonishing as they are, had still been inadequate to cause teeth, with their hard enamel, to grow as softer bone grows; and hence has arisen a provision perhaps more extraordinary still—a set of small teeth appear soon after birth, and serve the child until six or seven years of age: these then fall out, and are replaced by larger ones, which last for life, and the number is completed only when the man or woman is full-grown, by four more teeth which rise to fill up completely the now spacious jaw. These last are called wisdom teeth.

The spine or back-bone has as much of beautiful and varied mechanism in it as any single part of our wonderful frame. It is the central pillar of support or great connecting chain of all the other parts; and it has, at the same time, the office of containing within itself, and of protecting from external injury, a prolongation of the brain, called the spinal marrow, more important to animal life than the greater part of the brain itself. We shall see it uniting the apparent incompatibilities of great elasticity, great flexibility in all directions, and of great strength both to support a load and to defend its important contents.

Elasticity.—The head rests on the elastic column of the spine, as the body of a carriage rests upon its springs; for between each two of the twenty-four vertebræ or distinct bones of which the spine consists, there is a soft perfectly elastic *intervertebral substance*, about half as bulky as the vertebra, and yielding readily to any sudden jar. The spine, moreover, if viewed sideways, is seen to be waved or bent a little like an italic *ſ*, and for this reason also, yields to any sudden motion of the body. This bending might seem a defect in a column intended to support weight, but the disposition of the muscles about it just counteracts so as to leave the elasticity of the bend, and a roomy thorax, without any diminution of strength.

Flexibility.—The spine is like a chain, because it consists of twenty-four distinct pieces, all joined by smooth rubbing surfaces, and allowing a degree of motion in all directions. A little motion comparatively between each two pieces becomes a great extent of motion in the whole spine, and the articulating surfaces are so many, and so exactly fitted to each other, and connected by such number and strength of ligaments, that the combination is really a stronger column than a single bone of the same size would have been.

The *strength* of the spine as a whole, is shewn in a man's easily carrying upon his head a weight heavier than himself. And a single vertebra is seen to be a strong irregular ring, or double arch, having a smooth inside, for the spinal marrow to rest in.

We have to remark, that the spine increases in size towards the bottom, in the justest proportion, as it has more weight to bear.

Considering the great number of parts forming the spine, and their so delicate mutual adaptation, one might suppose that injuries and diseases of the structure would be very frequent. The reverse, however, is the truth under ordinary circumstances; so that while hundreds and thousands of works have been published on the ailments of almost all the other parts of the body, it is only within a few years that spine affections have drawn the attention of medical men at all. The reason of this is twofold: 1st, that all which regards health and disease is now much more completely analized than formerly; and 2dly, that from a change recently introduced into the system of education for young ladies, a considerable proportion of them have grown to womanhood with weakened and crooked spines.—This subject merits farther consideration here.

To the well-being of the higher classes of animals, exercise of their various parts is as necessary as nourishment, and if it be withheld by any cause during the period of growth, the body is often crippled permanently. The overflow of life and energy which nature has given to young creatures to prompt them to useful exertion, is seen in the ever-changing occupation of a child, in the quick succession of its ideas, in its jumping and skipping and using all sorts of round-about action that may expend muscular energy, instead of seeking, as in after life, to accomplish its ends in the shortest ways: and the same law is illustrated among the inferior animals, by the play of kittens, puppies, lambs, &c.

Strongly as nature has thus expressed herself upon the important subject of exercise among the young, tyrant fashion, with a usual perversion of common sense, has of late times, in England, formed a school discipline for young women of the higher classes, which wars directly with nature's dictate: and the consequences have been such, that a stranger arriving here from China, might almost suppose it the design to make crooked and weak spines by our school discipline, as it is the design in China to make little feet by the iron shoe. The result is the more striking, because the brothers of the female victims, and who of course have similar constitutions, are robust, healthy, and well formed. A *peasant girl* is allowed to obey her natural feeling when her spirits are buoyant, and at proper times may dance, and skip, and run, until healthy exhaustion ask that repose, which is equally allowed; and she thus grows up strong and straight: but the *young lady* is receiving constant admonition to curb all propensity to such vulgar activity, and often, just as she subdues nature, she receives the praise of being *well-bred*. Her multifarious studies come powerfully in aid of the admonition, by fixing her for many hours every day to sedentary employment. This adoption of sedentary habits is not only hurtful, by preventing the natural extent and variety of exercise, and thereby weakening the whole body, but is rendered particularly injurious to the back, by the manner in which the sitting is usually performed. It would be accounted great cruelty to make a delicate young creature stand all day, because the legs would tire,—but this very cruelty is almost in constant operation against the back, as if backs could not tire as well as legs. When a girl is allowed to sit down because she has been long standing, great care is taken that the muscles of the back, which still remain in action as she sits, shall not be at all relieved; for, from the idea that it is ungraceful to loll, she is either put upon a stool which has no back at all, or upon a very narrow chair with a perpendicular back. The stool relieves her spine more than the chair, because it allows of bending in different ways, so as to rest the different sets of muscles alternately; but the chair forces her to keep the spine quite upright and nearly unmoved. The consequence soon is, that being first weakened generally, by sedentary habits, and the back being still farther weakened by excessive fatigue, the spine gives way in some part and bends, and the curvature becomes permanent. In this bending, the spine is sometimes partially rotated, so as to shew from behind that waving profile which should only be seen from the side. At other times the vertebræ and intervening substance merely become thinner on one side from the continued pressure and weakness. When a bend takes place in one situation, it immediately occasions an opposite bend above or below it, to bring the centre of gravity of the upper parts directly over the base again ; and hence the curve becomes double, like an Italic *ſ*.

When the inclination of the back has once begun, it is very soon increased by the means used to cure it. Strong stiff stays are put on, to support the back as it is said, but which in reality, by preventing those muscles from acting which are intended by nature as the supports, cause them to lose their strength, and when the stays are withdrawn, the body can no longer support itself. Longer sittings in the narrow upright chair are then recommended, and sometimes the back is forcibly stretched by pullies, or the patient is kept all day and night lying on an inclined board, and losing her health, &c. &c. The only things forgotten are to give proper exercise in the air, and to let the child rest when she is not taking such exercise. The prejudice had at last grown up, that strong stays should be put upon children very early to prevent the first beginnings of the mischief, and that a child should always be made to sit on the straight-backed chair, or to lie on the hard plane: and it is probable, that if these cures and preventives had been adopted as universally and strictly as many deemed them necessary, we should not have in England a young lady whose back would be straight or strong enough to bear the weight of her shoulders and head. It would disgust us to see the attempt made to improve the strength and shape of a young race-horse or greyhound, by binding tight splints or stays round its beautiful young body, and then tying it up in a stall; but this is the kind of absurdity and cruelty so commonly practised in this country towards what may well be called the most faultless of created things.

A pernicious prejudice, with respect to this curvature or distortion of the spine, long existed, *viz.* that it was a scrofulous affection; and many mothers hid it from those about them, and sought remedy from quacks far from home. Indeed until within a few years, it was altogether the province of some irregular members of the profession to manage spine diseases, and it became to them a rich source of wealth, for many of their remedies being calculated to prolong the evil, they did not soon lose their patients.

A man of considerable note in this class, lately pronounced a case of crooked spine, which fell into his hands, to be a dislocation of the whole middle part of it; and in the published account of the treatment which he said had effected a cure, he had the folly to assert, that each day, by his various operations, he replaced one vertebra of the number dislocated, until at last the whole were restored. He thus accused himself of having torn each vertebra from those about it, and of treating a dislocated spine as that man would treat a dislocated arm, who should break the bone into pieces of an inch, and replace these successively, instead of letting the whole return as a single piece, in the common way.

The practice in spine cases, however, has now fallen into the hands of the informed profession, and science having detected the true causes of the evil, its frequency is already diminished. It has been shewn that nothing is easier than to prevent it, and that the best cures are those conducted on the general principles of improving the health of the patient, and of using exercises which directly strengthen the affected part.

Some might expect here a long description of machines employed in the treatment of such affections: but fortunately the list of the only ones which are useful or safe is very short:—a sofa to rest upon, and choice of pleasant means of taking exercise: such as the skipping-rope, shuttlecock, dumb-bells, a rope-ladder to climb, a winch to turn, &c.: and sometimes, where it is much desired that the young lady should continue her lessons of music in a sitting attitude, a chair may be used, having an overhanging canopy or crane, from which straps descend to support the head and shoulders, while proper weights, fixed to cords from these straps, and acting over pullies, give the required support. The author has had a small light crane of wood made, which answers the purpose well, and may be attached to a common chair. It would be out of place here to detail those particulars of constitutional treatment, which so usefully aid the effects of suitable exercise.

The Ribs.—Attached to twelve vertebræ in the middle of the back, are the ribs or bony stretchers of the cavity of the chest, constituting a structure which solves, in the most perfect manner, the difficult mechanical problem of making a cavity with solid exterior, which shall be capable of dilating and contracting itself. Each pair of corresponding ribs may be considered as forming a hoop, which hangs obliquely down from the place of attachment behind; and when the forepart of all the hoops is lifted by the muscles, the cavity of the chest is enlarged.

We have to remark the double connexion of the rib behind, first to the body of the vertebra, and then to a process or projection from it, thus effecting a very steady joint, and yet leaving the necessary freedom of motion; and we see the forepart of the rib made of flexible cartilage, so as to allow the degree of motion required there, without the complexity of a joint, and admirably guarding by its elasticity, against the effects of sudden blows or shocks.

The muscles having their origin on the ribs and going to the bone of the arm, afford us an example of action and reaction being equal and contrary. When the ribs are fixed, these muscles move the arm; and when the arm is fixed, as by resting on a table or chair, the same muscles move the ribs, as is seen in fits of asthma and dyspnea.

The human skeleton, with its naked ribs, is so associated in the common mind with ideas of death and loss of friends and all the terrors of doubtful futurity, that to most persons it is an object of abhorrence: but to the philosophic mind, which rises superior to place and time, the admirable and evident adaptation of all the parts to their purposes, and parts which being purely mechanical are perfectly understood, makes it an object of the most intense interest, independently of all professional considerations. Such mechanism reveals, by intelligible signs, some of the attributes of the Creator, and a man may be said sublimely to converse with Deity, who contemplates and understands it aright.

The *Shoulder-joint* is remarkable for its great extent of motion, combined still with great strength. The round head of the shoulder-bone rests upon a shallow cavity in the shoulder-blade, that it may turn freely in all ways; and the danger of dislocation from this shallowness is guarded against by two strong bony projections above and behind. To increase the range of motion here to the greatest possible degree, the shoulder-blade itself, which has the socket of the arm in it, slides about upon the convex barrel of the chest, and has its motion limited only by a connexion with the sternum through the clavicle or collar-bone.

The *scapula* or *blade-bone* is extraordinary as an illustration of all the rules for combining lightness with strength. It has the strength of the arch in being a little concave, like a dished wheel already described, and its substance is chiefly collected in its borders and spines, with thin plates between, as the strength of a wheel is collected in its rim, and spokes, and nave.

In the bones of the arms, considered as levers, the moving muscles are attached very near to the fulcra and very obliquely, and working therefore through so short a distance comparatively with the resistances overcome at the extremities, they require to be of great strength. It has been calculated that the muscles of the shoulder-joint, in the exertion of lifting a man upon the hand, pull with a force of two thousand pounds.

Notwithstanding all the securities to the shoulder-joint now described, in the infinite variety of twists, and falls, and accidents to which man is liable in the busy scene of society, the joint is frequently dislocated, that is, the rounded head of the bone of the arm slips from its socket, with instant lameness as a consequence.

In the treatment of dislocations and fractures of the frame-work of the human body, the surgeon cannot avoid displaying strikingly either his skill in his profession or his ignorance. With what ease does the displaced arm or thigh-bone return under the guidance of the skilful hand! and to what horrible and often unavailing torment is the victim subjected, when in such a case ignorance dares the attempt! It is positive pain to a vivid imagination to look into the records of ancient surgery, and to be made present, as it were, to the stretching of patients on the rack with pullies and powerful engines, to do what better information could have so easily accomplished without such means. And would that the records of modern times, were less remarkable from the instances they contain of individuals crippled for life by bad practice. Nothing can now insure impunity and a quiet conscience to a practitioner in this branch, but a familiarity with the laws of mechanical philosophy, and a perfect knowledge of anatomy.

With our present information on these subjects, we are surprised at the detail of the practices and errors adopted in former times, and promulgated by authors of the highest credit, from ignorance of mechanics. It would hardly be believed that Mr. Pott, one of the glories of English surgery, held and taught that, in reducing a dislocation of the shoulder or hip, it was useless to pull by the hand or foot, because the intervening joints prevented the strain from reaching the part desired.

Some surgeons, possessing a certain degree of knowledge in mechanics, but only that degree which is dangerous, having heard that the lever was a powerful engine, have tried to replace bones solely by leverage, as it was called; that is, a man's dislocated arm has been placed over the back of a chair as a fulcrum, or over the top of a door, and the weight of the suffering body hanging to it on one side as the resistance, force has been applied to the other side, enough sometimes to break the bone, or to tear away all the ligaments and soft parts about the joint.

Others, in the same way, having learned the effects of the pulley, have wished to do all by irresistible extension, and have torn muscles and ligaments from their attachments.

It is not the business of this work to enter into a minute examination of the accidents befalling the body, which require mechanical skill for their proper management, for this would be to deliver a course of practical surgery: but it is wished to teach the student those valuable general principles, which furnish constant direction and solve most difficulties. Possessing these principles, and good sense, he will often be a more effective minister of his art than a man full of learned precedents, who wants them. To make this lesson more striking to his young readers, the author here takes occasion to mention that when he was so young that he could not yet have had much practical experience, he was thrown into a situation where a heavy medical charge devolved upon him; and through accidents among a numerous crew during an eventful voyage, and intercourse with the savage inhabitants of unfrequented coasts, in twenty-six months, he had more practice in dislocations, fractures, and singular wounds, than falls to the lot of many during a long life. It was then that he became fully aware of the importance to the medical man of general philosophical principles; and that his peace of mind, left after the voyage, was much owing to the circumstances which had made him look carefully at the body through such media.

The os humeri, or bone of the upper arm, is not cylindrical, but like most of the other bones called cylindrical, it has ridges to give strength, on the principle explained in the chapter on strength of materials.

The elbow joint is a correct hinge, and so strongly secured that it is rarely dislocated without fracture.

The fore arm consists of two bones and a strong membrane between them. Its great breadth from this structure, serves the purpose of giving abundant space for the origin of the many muscles that go to move the hand and fingers: and the very peculiar connexion of the two bones, gives man that useful faculty of turning the hand round, into what are called the positions of pronation and supination.

The old surgeons, who acted often by rules of routine rather than by reasons, in the accident of fracture to one or both bones of the fore arm, often applied a tight bandage, which pulled the bones close to each other at the fractured part, and thus injured the shape and strength of the arm.

The wrist. The many small bones forming it, have a signal effect in deadening to the parts above the shocks or blows which the hand receives.

The annular ligament, is a strong band passing round the joint, and keeping all the tendons descending from the muscles above to the fingers, close to the joint. It answers the purpose of so many fixed pullies for directing the tendons; without it they would all, on action, start out like bow strings, producing deformity and weakness.

The human hand is so admirable, from its numerous mechanical and sensitive capabilities, that it was at one time a received opinion, that man's superior reason depended on his possessing such an instructor and such a servant. It is certainly true, that reason with hoofs instead of fingers, could never have raised man much above the brutes, and probably could not have secured the continued existence of the species—but the hand is no more than a fit instrument of the godlike mind which directs it.

The pelvis, or circle of bone on which the spine rests, and from which the legs spring, is a double arch. The spine rests on the os sacrum or keystone of the upper arch, and the legs support the piers; and to resist the horizontal thrust which tends to separate the piers, a second arch, called the pubes, joins them below. The pelvis answers many other purposes than that of mere support. The opening through the circle looks downwards and backwards, and the double arch protects the uterus and ovaries and the excretory ducts.

As if nature were sparing of material and weight, the pelvis is another instance of evident contrivance to combine strength with lightness. The thyroid hole and ischiatic notches are merely deficiencies of bone where solidity could not have given additional strength.

The hip joint exhibits the perfection of the ball and socket articulation. It allows the leg to move round in a circle, as well as to have the great range of backward and forward motion, observed in the action of walking. It is in seeing the elastic tough smooth cartilage which lines the deep socket of this joint, and the similar glistening covering of the ball or head of the thigh-bone, and the lubricating synovia poured into the cavity by appropriate secretories, and the tough ligaments giving strength all around, that one remarks how far the most perfect of man's works falls short of the mechanism of nature.

The thigh-bone is remarkable for the projections called trochanters, to which the moving muscles are fixed, and which lengthen considerably the lever by which the muscles work. The shaft of the bone is not straight, but has a considerable bend forward in its middle. Short-sightedness might suppose this a weakness, because the bone is a pillar supporting a weight, but the bend in reality gives it the strength of the arch, to bear the action of the mass of muscle called *vastus*, which lies upon its forepart.

The knee is a hinge joint of complicated structure, and claims the most attentive study of the surgeon. The rubbing parts are flat and shallow, and therefore have little strength from form; but the joint derives security from the numerous and singularly strong ligaments which surround it. The ligaments on the inside of the knees resemble, in two circumstances, the annular ligaments of joints, *viz.* in having a constant and great strain upon them, and yet, instead of yielding, in becoming stronger always in proportion as the strain increases. The line of the leg bends inwards a little at the knee in the most perfect shapes, and in many persons it does so very much; but we do not find the bend to increase with age: the legs of many weakly in-kneed children become straight by exercise alone. This inward bend at the middle joint of the leg, throwing a great strain on the flexible ligaments, gives an elasticity to the limb, which is useful in jumping, running, &c.

In the knee there is a singular provision of loose cartilages, which have been called friction cartilages, from a supposed relation in their use to friction wheels; but their real effect seems to be to accommodate the ends of the rubbing bones to each other in the different positions of the joint.

Under the head of pneumatics, we shall find that the bones forming the knee are held together, independently of their ligaments, by a constant pressure of the atmosphere, amounting to upwards of sixty pounds.

The great muscles on the forepart of the thigh are contracted into a tendon a little above the knee, and have to pass over and in front of the knee to reach the top of the leg, where their attachment is. The tendon, in passing over the knee, becomes bony, and forms the patella or knee-pan, often called the pulley of the knee. This peculiarity enables the muscles to act more advantageously, by increasing the distance of the rope from the centre of motion; and the patella becomes also a sort of shield or protection to the forepart of this important joint.

The leg below the knee, like the fore-arm already described, has two bones. These offer spacious surface of origin for the numerous muscles required for the feet, and form a part of greater strength than the same quantity of bone as one shaft would have done. The individual bones also are angular instead of round, thus having greater power to resist blows, &c.

The ancle-joint is a perfect hinge of great strength: there is in front of it an annular ligament, by which the tendons passing downwards to the foot and toes are kept in their places. One of these tendons passes under the bony projection of the inner ancle, in a smooth appropriate groove exactly as if a little fixed pulley were there.

The heel, by projecting so far backwards, is a long lever for the strong muscles which form the calf of the leg, and terminate in the tendo achillis, to act by. These muscles, by drawing at the heel, lift the body, in standing on the toes, in walking, in dancing, &c. In the negro foot the heel is so long as to be ugly in European estimation; and its great length rendering the effort of smaller muscles sufficient for the various purposes, the calf of the leg in the negro is smaller in proportion than in other races of men.

In a graceful human step the heel is always raised before the foot is lifted from the ground, as if the foot were part of a wheel rolling forward; and the weight of the body rests for the time on the fore part of the foot and toes. The muscles forming the calf of the leg lift the heel, as just described, by drawing at the tendo achillis, and produce a bending of the foot in a corresponding degree. But where strong wooden shoes are used, or any shoe so stiff that it will not yield and allow this bending of the foot, the heel in walking is not raised at all until the whole foot rises with it, so that the muscles of the calf are scarcely used, and in consequence soon dwindle in size and almost disappear. Many of the English farm servants wear heavy stiff shoes, and in London it surprises one to see the drivers of country waggons, with fine robust persons in the upper part, but with legs which are fleshless spindles, producing a gait most awkward and unmanly. One regrets that, for the sake of a trifling saving, fair nature should be thus deformed. The wives and sisters of these men, and their brothers who are otherwise employed, are not thus misshapen.—An example of an opposite kind is seen in Paris, where, as there are no side pavements in the streets, and the ladies consequently walk almost constantly on tiptoe, the great action of the muscles of the calf has given a conformation of the leg and foot, to match which the Parisian belles proudly challenge all the world. They are not aware, probably, that it is a defect in their city to which the peculiarity of their form is in part owing.

A person confined to bed for a week or two by sickness, has generally to remark a much greater wasting of the legs than of the arms; the reason is, that the muscles of the leg in ordinary cases are more in use than those of the arms, and their usual bulk is in part owing to this; inaction produces, therefore, a greater change in them, than in others, which have a certain magnitude independently of use.

Facts of this kind, and the known truth that, by gymnastic exercises and training, the form of the body may be changed, shed important light upon the subject, at present so near to the hearts of many English mothers, *viz.* the weak and crooked backs of their daughters.—Strong stays, which do the duty of the muscles placed by nature around the spine, cause these muscles to dwindle from inaction, and afterwards the back bends or twists when the support of the stay fails or becomes unequal. Stays, therefore, can neither make strong and well-formed backs originally, nor can they be a remedy after the weakness has appeared. A healthy young woman from the country, whose spine lies deep between the firm cushions of muscle which support it, if braced up in tight stays, according to town fashion, will exhibit at the end of a few months such a wasting of the flesh that the points of bone in the spine may be counted by the eye all the way down.

The arch of the foot is to be noticed as another of the many provisions for saving the body from shocks by the elasticity of the supports. The point of the heel, and the balls of the toes, are the two extremes of the elastic arch, and the leg rests between them.

Connected with elasticity, it is interesting to remark how imperfectly a wooden leg answers the purpose of a natural leg. With the wooden leg, which always remains of the same length, the centre of the body at each step, must describe a portion of a circle of which the bottom nob of the leg is the centre, and the body is therefore constantly rising and falling; while with the natural legs, which are easily made a little shorter or longer by gentle flexure at the knee, in different parts of the step, the body is carried along in a manner perfectly level. In like manner, a man riding on horseback, if he keep his back upright and stiff, has his head jolted by every step of the trotting animal; but the experienced horseman, even without rising in the stirrups, can carry his head along quite smoothly, by letting the back yield a little at each movement; the back thus acts as a bent spring does in smoothing the motion of a carriage.

In a general review of the skeleton, we have to remark, 1st, the nice adaptation of all the parts to each other, and to the strains which they have to bear; as in the size of the spinal vertebræ increasing from above downwards—the bones of the leg being larger than those of the arm, and so on. 2dly, The objects of strength and lightness combined, as by the hollowness of the long bones—their angular form—their thickening and flexures in particular places where great strain has to be borne—the enlargement of the extremities to which the muscles are attached, lengthening the lever by which these act, &c. 3dly, We have to remark the nature and strength of material in different parts being so admirably adapted to the various purposes which they serve. We have bone, for instance, in one place nearly as hard as iron, where, covered with enamel, it has the office of chewing and tearing all kinds of matter used as food; in the cranium, again, it is softer, but tough and resisting; in the middle of long bones it is compact and little bulky, to leave room for the swelling of the muscles lying there, while at the end it is large and spongy, with the same quantity of matter, to give a broad surface for articulation; and in the spine, the bodies of the vertebræ, which rest on an elastic bed of intervertebral substance, are light and spongy, while their articulating surfaces and processes are very hard. In the joints we see the tough elastic smooth substance called cartilage covering the ends of the bones, defending and padding them, and destroying friction. In infants we find all the bones soft or gristly, and therefore calculated to bear with impunity the falls and blows unavoidable at their period of life; and certain parts remain cartilage or gristle for life, where this is necessary or useful, as the anterior extremities of the ribs. About the joints we have to remark the ligaments, binding the bones together, and possessing a tenacity scarcely equalled by any known substance; and that the muscular fibres, whose contractions move the bones and thereby the body, because they would have made the limbs clumsy even to deformity had they all passed over the joints to the parts which they have to pull, attach themselves at a convenient distance, to a strong cord called a tendon, and, like a hundred sailors at a rope, make their effort effective at any distance. The tendons are remarkable for the great strength which resides in their slender forms. Such, then, is the skeleton or general frame-work of the human body—less curious and complicated perhaps than some other parts of the system which we have yet to examine, but so perfect and so wonderful, that few minds can attentively consider it without emotion.

The living force of man has been used as a working power in various ways, such as in turning a winch—pulling at a rope—walking in the inside of a large wheel to move it, as a squirrel or turnspit dog moves his little wheel, &c. Each of these has some particular advantage; but the mode in which, for many purposes, the greatest effect may be produced, is for the man to carry his body only up to a height, and then to let it work by its weight in descending. A bricklayer's labourer will be able to lift twice as many bricks to the top of a house in the course of a day, by ascending the ladder without a load and raising brick of nearly his own weight over a pulley in descending, as he can lift by carrying the bricks and himself up together, as is still usually done.

Reflection would naturally anticipate such a result, independently of experiment, for the load which a man should be best able to carry, is surely that of his own body, from which he can never free himself. Accordingly the strength of muscles and disposition of parts are all such as to make his body appear light to him.

The question which was agitated with such warmth some time ago, as to the propriety of making men and women work on the treadmill, receives an easy decision here. They work by climbing on the outside of a large wheel or cylinder, which turns by their weight, and they advance upon it just as fast as it turns, otherwise they fall from their proper situation. On the outside of the cylinder there are projections or steps for the feet, and the action to the workers is exactly that of ascending an acclivity. Now as nature has formed the human body for climbing hills as well as for walking on plains; the work of the treadmill, under proper restrictions as to duration, seems as natural and healthful as any other. Its effects have now proved it to be so.

As animal power is exhausted exactly in proportion to the time during which it is acting, as well as in proportion to the intensity of force exerted, there may often be a great saving of it by doing work quickly, although with a little more exertion during the time. Suppose two men of equal weight to ascend the same stair, one of whom takes only a minute to reach the top, and the other takes four minutes, it will cost the first little more than a fourth part of the fatigue which it costs the second, because the exhaustion is in proportion to the time during which the muscles are acting. The quick mover may have exerted, perhaps, one-twentieth more force in the first instant, to give his body the greater velocity, which was afterwards continued, but the sloth supported his load four times as long.

A healthy man will run rapidly up a long stair, and his breathing will scarcely be quickened at the top; but if he walk up slowly, his legs will feel fatigued, and it will be some time before he can speak calmly.

For the same reason coach-horses are much spared by being made to gallop up a short hill, and being then allowed to go slowly for a little time, so as to rest at the top.

The rapid waste of muscular strength which arises from continued action, is shewn by keeping the arm extended horizontally for some time: few can continue the exertion beyond a minute or two. In animals which have long horizontal necks, there is a provision of nature in a strong elastic substance on the back or upper part of the neck, which nearly supports the head without muscular exertion at all.

Illustrative of the fact that exertion is saved in many cases by doing work quickly, we may recall the circumstance explained in a former part of the work, that a body thrown or shot upwards with double velocity, rises four times as high as it does with a single velocity, or half of the other.

“ *Instruments.*”

The following remarks regard some instruments used by medical men.

Midwifery forceps.—The blades beyond the joint or fulcrum being longer than the handles, the pressure on the child's head is less than that made by the hand, but it should always be kept present to the mind of him who uses the instrument. The substitute for the forceps proposed by the author, and described in the section on Pneumatics, it is hoped will save infant life and maternal suffering, in many cases where unpractised hands might try the forceps in vain.

The vectis, or lever used instead of the forceps to advance the child's head in parturition, is a very dangerous instrument in unskilful hands. In fact, whenever it is used as a lever, in the most common sense of the word, it is a piece of unskilful cruelty. Suppose any part of the pelvis to be made the fulcrum of this lever, the soft parts between the bone and the instrument are bruised with the whole force of the hand, and with twice or three times as much, if the resistance be nearer to the fulcrum than to the hand. The instrument can only be safely used, by the operator making one of his hands the fulcrum while the other is used as the power, or by his using one hand so as to answer both purposes; and then there is a resemblance between the action of the vectis and that of a hook.

The *Levator*, or lever for raising the broken and depressed portion of the scull in trepanning, has a fulcrum attached to it. Care should be taken to place this fulcrum where its pressure cannot be injurious.

The *circular*, or *crown saw* of the trephine, should be turned or worked with a quick motion and gentle pressure, for the reason given at page 156, when describing cutting instruments. The object is thereby sooner and better attained, and the head of the patient is shaken much less.

For the same reason, a light and quick motion of the saw should be used in dividing the bone in amputations: there is thus less jarring and an easier division.

In using the *amputation knife* also, the speed, neatness and success of the operation, are all favoured by mixing the drawing or saw motion in the knife with the pressure towards the bone.

These last observations are of a hundred similar, which might be made to prove of what vital importance it is for a surgeon to have familiarity with the use of tools or instruments. Perhaps a person cannot acquire this better than by amusing himself with some work of carpentry. Manual dexterity, and a little readiness at mechanical contrivance, so frequently prove of importance to persons in all stations, that it is surprising why in systems of general education, the matter has not received greater attention. If a handless or awkward man embrace the medical profession, and unfortunately attempt to practice surgery or midwifery, although he be possessed of brilliant intellect, he may fail in almost every thing which he attempts.

The Tooth Key is an instrument found in the hands of almost every body who pretends even to the lowest degree of skill in the healing art; and there is perhaps scarcely a day passing, in which teeth are not broken, and jaws splintered, and gums bruised even to sloughing, by the unskilful or awkward use of it. The common tooth key may be regarded in the light of a wheel and axle, with the hand acting on two spokes of the wheel to move it, while the tooth is fixed to the axle by the claw, and is drawn out as the axle turns. The gum and alveolar process of the jaw, form the support on which the axle rolls. The common errors of the operation of tooth-drawing by the key, are these.

1st. Turning it towards that side, where the adjoining teeth are too close for the moved tooth to pass, without either being broken itself, or breaking one of them. Sometimes two teeth are thus drawn instead of one.

2d. Neglecting the natural inclination of the tooth. By winding it round in the direction in which it already inclines, and in accordance with a bend which is generally found in the tooth itself, the operation is easy and safe; while if drawn in the opposite way, it not unfrequently breaks or splinters the part of the jaw-bone in which it sticks.

3d. If the tooth-claw is blunt, and its point slips high upon the tooth, it then acts almost directly across, and is very apt to break the tooth.

4th. And unless the axle or fulcrum of the key be made to rest as evenly as possible on the gum, it will tear or very much injure the gum. It should bear or rest, if possible, over the part of the bone in which the tooth is set, for otherwise, as when a back tooth is drawn with the instrument resting on a part considerably anterior to it, the twist produced is painful, and there is danger of splintering.—A man whose studies or reflection has suggested these remarks, and who then operates leisurely a few times on the dead subject, will be able to give instant and safe relief to most intense suffering. And it is hardly excusable in any medical man who may be placed where a dentist cannot be procured, to neglect acquiring a talent so easy and useful.

Some dentists pull teeth directly out by a strong forceps made for the purpose; others use a forceps in the manner of the tooth key, by resting one side of it on the gum as a fulcrum. In this case the resting side is formed like the bolster of a tooth key. But much more in all cases depends on the dexterity of the operator than on the form of the instrument.

Steel Trusses for ruptures are one of the blessings to suffering humanity, which modern ingenuity has supplied. From the unhealthy employments of some men in society, and the dissipation or unnatural modes of living of others, debilitated constitutions are frequent, and are often transmitted to offspring. One of the lamentable effects is that weakness of the sides of cavities in particular points, which allows the protrusion under the skin, of the living parts from within. The occurrence is called hernia or rupture: the most common hernia is that of the intestines, through the groins.

Formerly this occurrence disabled for life. A man who had it was discharged from the army or navy; he could not ride on horseback, or take usual exercise; he could not lift a weight, and in a word, he was often a miserable burden to himself and others. Now by fitting the pad of a good steel truss to the part, the rupture is restrained permanently, and as perfectly as it could be for a moment by the hand of a skilful surgeon. The truss is put on and off with almost as little reflexion or trouble as a part of the ordinary dress, and the man becomes again as fit for all the duties of life as if he were without his ailment.

The old form of the steel truss was that of a half or three-quarter hoop, so bent and tempered, that when put upon the patient, one end with a pad upon it, pressed inwards with a given force on the opening by which the rupture protruded. The defects in this kind of truss are, that it is difficult to make it fit exactly; it is rather troublesome to put on and off: and it bends or presses disagreeably all round the body.

The other kind, which is free from these defects, consists of a little more than half a hoop, with a pad at each end: one of the pads supports the weakness, and the other rests upon the centre of the back, to bear all the strain there, while the hoop itself hangs loosely on the side of the body. This truss almost falls into its place of itself and needs no fastenings: the same truss fits all persons of one size, whatever their shape; and the strength may be adjusted by changing the number of the springs of which the hoop consists.

Tourniquets, crutches, splints, &c. &c. are so simple in all respects as not to merit special notice here.

This section contains some of the reflections which occur to a person familiar with mechanical philosophy, in contemplating the human skeleton, and the more complete such a person's knowledge is of anatomy, physiology, surgery, and medicine, the more numerous will be the professional objects on which this philosophy will shed a light dissipating doubt and error. The author has not entered into more minute detail, because it would have been encroaching upon the office of those who teach particular departments; and because he thinks that any one who is not enabled by the examples here given, to make the applications of the general laws to all possible cases, may account the study of the healing art unsuited to the faculties with which he is endowed.

CHAPTER III.

THE DOCTRINE OF FLUIDS—ARRANGED UNDER THE TITLES OF *HYDROSTATICS* AND *HYDRAULICS*, FOR LIQUIDS, AND OF *PNEUMATICS*, FOR AIRS. (**Read the synopsis, page 1.**)

SECTION I.—HYDROSTATICS.

ANALYSIS OF THE SECTION.

The particles in a fluid mass are freely moveable among each other, so as to yield to the least disturbing force. Hence:

1. *In fluid submitted to compression, the whole mass is equally affected, and the compression operates in all directions. A given pressure, therefore, made upon one square inch of the surface of a fluid confined in a vessel, as by a cork or plug forced inwards upon it, is instantly communicated to every square inch of the vessel's surface, however large, and to every inch of the surface of any body immersed in the fluid.*
2. *In any fluid, the particles that are below, bear the weight of those that are above, and there is, therefore, a pressure within the mass, increasing exactly with the perpendicular depth, and not influenced by the size, or shape, or position of the containing vessel.*
3. *The open surface of a fluid is level; and if various pipes or vessels communicate with each other, any fluid admitted to them will rise to the same level in all.*
4. *A body immersed in a fluid displaces exactly its own bulk of it, which having been just supported by the fluid around, the body is supported with exactly the same force, and must sink or swim according as it is heavier or lighter than the fluid displaced. The force with which a body is held up in a fluid being the exact weight of its bulk of that fluid, by comparing this with the weight of the body itself, the comparative weights, or the* specific gravities, *are found.*

"*Hydrostatics*"

is a term from the Greek, designating what regards *water at rest*, and the sister term *hydraulics*, designates what regards water in pipes or in motion.

"*Fluid.*"

It was explained in chapter first, that the same atoms may exist in the form of a solid or of a fluid, and, as a fluid, they may either be a dense liquid like water, or a light elastic mass like air. A pound of ice, or a pound of water, or a pound of steam, differ only in the particles being more or less distant from each other, owing to the different quantities of heat among them. In the first case, they are comparatively near, and are held together by attraction, as strongly as if they were spitted or glued to each other; in the second case, the repulsion of heat seems just to balance attraction, and to leave the particles at perfect liberty to glide about among each other without friction; and in the third case, the repulsion overcomes the attraction completely, and the particles separate to a great distance, as if held apart by some bulky elastic medium. Simple and satisfactory as this explanation appears, there are a few facts belonging to the department which will not range under it: such, for instance, as that water in cooling down from forty degrees to the freezing point increases in volume, although at all other temperatures it contracts in cooling, like things in general;—and that baked clay contracts instead of dilating, in proportion as it is more heated.

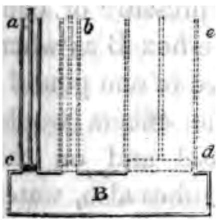
Whether matter be in the solid or fluid form, the properties of the individual atoms remain unchanged; and, as in the chapter on mechanics, we found so many important modifications of effect produced by the circumstance of solid cohesion among them, in this chapter on fluids, we shall find as many important results arising from the circumstance of non-cohesion or fluidity.

In a liquid, the particles are comparatively near to each other, but they seem not to be in actual contact; for the mass may be condensed indefinitely by pressure. The force required, however, to change the volume of a liquid in any sensible degree, is so great, that until the improved means of experiment contrived very recently, liquids were accounted absolutely incompressible. In aeriform fluids, on the contrary, each particle, under common circumstances, has about two thousand times as much space to itself as when in the liquid or solid state; and hence the reason why these fluids are so extensively compressible and dilatable, or elastic, as they are called. On account of this elasticity, they exhibit so many curious phenomena, in addition to those of mere fluidity, that the consideration of them requires to be gone into apart, and forms the branch of the subject called Pneumatics.

" *In a quantity of fluid submitted to compression, the effect is equally diffused throughout the whole, and is felt in all directions. A given pressure, therefore, made upon one inch of the surface of a fluid confined in a vessel, as by a cork or plug* *forced inwards upon it, is instantly felt or borne by every inch of the surface of the vessel, however large, and by every inch of the surface of any body immersed in the fluid."*

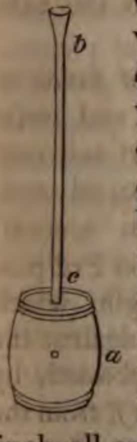
The truth stated in the above paragraph is of great importance, both from the useful applications which have been made of it in the construction of machinery, and from its explaining so many remarkable phenomena.

When a man compresses in his hand a bladder full of air, he does not believe that the air is at all more compressed immediately under his fingers than in every other part of the bladder; and of course the bladder's surface generally must be pressing the air as much as those parts do on which his fingers rest, and must be bearing a reaction or resistance of the air in an equal degree. Every single particle of air also must be acted upon on every side; and if a small opening be made in the bladder, at whichever side it be, the air will issue from it with equal readiness.



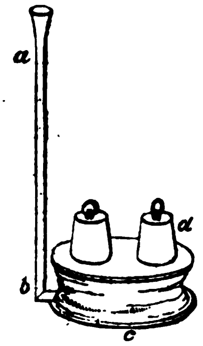
In like manner, if a close vessel B be filled with water, and into the top of it a tube *a c* be screwed, and if then, by means of a cork or moveable plug in the tube at *c*, the surface of the water in the vessel be pressed upon with a force of one pound, the water throughout will be condensed in proportion to the pressure, and every other portion of the vessel B, of equal surface with *c*, will be keeping up the condensation just as much as *c*, and will be bearing the resistance or elasticity of the water to the extent of one pound. And if there were another similar tube *b*, also with a plug, screwed into the top of the box B, the force of one pound depressing the plug *c* would push up the plug *b* with the same force; and if there were many other similar tubes and plugs, by acting on one, all would be equally affected; and a plug or piston of double size would be twice as much affected as the smaller one *c*; and a plug *d*, ten times the size, would be lifted with a force of ten pounds. Hence it appears that, through the medium of confined fluid, a force of one pound, acting upon an inch square of the fluid surface in a vessel, may become a bursting force of ten or a hundred or a thousand pounds, according to the size of the vessel, or may be used as a mechanical power to overcome a force much more intense than itself.

If in the above figure the tube *a* were just big enough to contain one pound of water, the plug *c* might be withdrawn from it, and the tube being then filled with water, the same pressure or condensation would take place in the box B as when the plug was pressed with the force of one pound; and of course exactly the same effects would follow on the sides of the vessel and on the other pistons; and if in the other tubes also, water were substituted for the pistons, it is evident that, to balance, it would require to stand as high in them as in the tube *a c*.—This extraordinary result has been called the hydrostatic paradox, where the weight of one pound of water is seen through the medium of extended fluid to be producing a pressure of hundreds or of thousands of pounds. Yet, in this fact there is nothing in reality more paradoxical than that one pound at the long end of a lever should balance ten pounds at the short end: indeed it is but another means, like the contrivances called mechanical powers, described in the last chapter, of balancing different intensities of force, by applying them to parts of an apparatus which move with different velocities. Here the tube *a* being ten times smaller than the tube *e*, the piston in *a* must descend ten inches to raise the greater piston in *e* one inch.

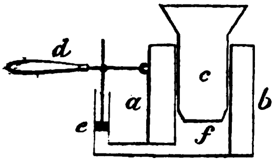


This law of fluid pressure is rendered very striking by the experiment of bursting a strong cask by the weight or action of a few ounces of water. Suppose a cask *a* already filled with water, and that a long small tube *b c* is then screwed tightly into its top, which tube will contain only a few ounces of water; by pouring these few ounces into the tube, the cask will be burst. In explanation of this, it is unnecessary to say more than that if the tube have an area of a fortieth of an inch, and contain half a pound of water when filled, it produces a pressure of half a pound upon every fortieth of an inch all over the interior of the cask; and this is more than the cask can bear.

The same effect is seen in what is called the *hydrostatic bellows.* It consists of a long small tube *a b*, into which water is poured to enter the body of the apparatus at *c*, which resembles the common bellows, in having wooden boards above and below, and strong leather connecting them. If the tube *a b* holds an ounce of water, and has itself only one-thousandth of the area of the top of the bellows, an ounce of water in the tube will balance weights of a thousand ounces placed on the top of the bellows at *d.* If mercury were substituted for water in this machine, the effect would be fourteen times greater, because mercury is fourteen times heavier in the same bulk: and if a man stand on the bellows, by blowing into the tube with his mouth, he may raise himself.



Mr. Bramah applied this property of fluids in the construction of his most powerful and useful *hydrostatic press.* It consists of a short and very strong pump barrel *a b*, (shewn here in section) with a solid piston *c* of proportionate strength, which piston is pushed against the thing to be compressed, by water driven into the barrel beneath, at *f*, from the small pump *e.* If the small pump have only one-thousandth of the area of the large barrel, and if a man, by means of a lever handle *d* to the



small pump, press its piston down with a force of five hundred pounds, the great piston will rise with a force of one-thousand times five hundred pounds, or more than two hundred tons. Nothing can withstand the power of such a press, whether to condense materials, to raise great weights, or to tear things asunder against the most powerful resistance.

The Dilator is a surgical instrument of extensive application, of which the action depends on this principle of fluid pressure. It was proposed by the author some years ago, and was brought to great practical perfection by his brother, Dr. James Arnott (now superintendant surgeon in the service of the Hon. East-India Company), in whose publication on diseases of the urethra, &c. it is minutely treated of. Many professional men in this country doubted of its power, from their not being aware of the nature of fluid action; but it is in reality a hydrostatic press, allowing the operator to act with the most gentle or most energetic force. Farther remarks are made upon it in the medical section which follows this chapter.

"*In any fluid, the particles that are below, bear the weight of those that are above, and therefore there is a pressure among them increasing in exact proportion to the perpendicular depth, and not influenced by the size or shape or position of the containing vessel.*"

That this must be true, where the atoms have gravity, is evident from reflecting, that the upper layer is supported by the second, and this with its load by the third, and the third with its double load by the fourth, and so on. This truth is experimentally proved by putting different heights of liquid into an upright tube, of which the bottom is closed by a flap sustained by a spring or lever, which indicates the force acting on it. And what is true of the entire column of water in the tube, is true of any single line of atoms in that column; just as it would be true of a line of bricks piled one above another, and maintained upright.

A tube of which the area is an inch square, holds nearly a pound of water in two feet of its length; hence the pressure in water at any depth, whether on the side of a vessel or on its bottom, or on any body immersed, is nearly one pound on the square inch for every two feet of depth.

The striking effects from the increase of pressure in a fluid, at great depths, are of course most commonly exhibited at sea. The following instances will illustrate them.

If a strong square glass bottle, empty, be firmly corked, and then sunk in water, it is generally crushed inwards by the extreme pressure, before it reaches a depth of ten fathoms.

When a ship founders near the shore, on breaking up, the wreck generally floats and is cast upon the beach; but when a ship sinks in deep water, the great pressure forces water into the pores of the wood, and makes it so heavy that no part can ever rise again to reveal her fate.

A bubble of air or of steam, set at liberty far below the surface of water, is small at first, and gradually enlarges as it rises.

A man who dives deep, suffers much by the compression of his chest, from the yielding of the elastic air within, under the strong pressure. This limits the depth to which divers can safely go.

It is not known whether there is a limit to the pressure which fishes can bear with impunity, but they are chiefly found living in the shallower waters on coasts, or on banks in the midst of the ocean, such as the banks of Newfoundland, the Dogger-bank, and other fishing stations out at sea. In rounding the Cape of Hood Hope, at a considerable distance from land, ships pass over the bank of Lagullas, where a hook let down, with a bit of red rag as a bait, immediately secures a codfish.

It is easy to prove the compressibility of water, by sending a vessel down into the deep sea. Suppose the vessel to be made with only one entrance through a small round opening, to which, instead of a cork, a close-fitting sliding rod is adapted. If the vessel be then filled with water, and the rod be inserted in the opening, on sending it down into the sea, the pressure around pushes the rod into the vessel, in a degree proportioned to the yielding or compression produced in the water within; and if there be a stiff-sliding ring on the rod, to indicate afterwards how far it had been driven inwards, it is evident that the apparatus may serve to shew the degree of compression at any depth. At a thousand fathoms the condensation is one-twentieth of the bulk.

The pressure in any part of an open fluid, operates, of course, in all directions, as already described in the case of a confined fluid.

If a corked empty bottle be sent down into the sea, the cork is forced inwards at a given depth, without regard to the direction in which the mouth of the bottle may happen to point.—A bottle cork carried far under water, is not flattened as if by an unequal pressure, but is reduced in all its dimensions, so as to appear a phial cork.

If a vessel containing water have an opening in the side, covered by a valve or flap so contrived as to tell the force acting to keep it close, it is found that the water tends to escape just as powerfully through such an opening as if it were in the bottom, with the same elevation of water over its centre. And different openings in the side of a vessel require to be closed with forces exactly proportioned to the heights of liquid above them.

In a square-sided vessel full of water, the whole pressure on any side, is just half of what it is or would be on an equal extent of bottom; because the centre of the side is just half as deep as the bottom. Where the bottom and side meet the pressure is equal on both, but it gradually diminishes on the side, as the depth is less, and at the middle, being only half as much as at the bottom, and above the middle being just as much less than half, as below it is more than half, it amounts to an exact half in the whole.

The pressure on the side of a narrow vessel is just as great as on the side of a wide vessel, with the same depth of fluid: because, as now explained, it depends entirely on the extent of surface acted upon and the depth of liquid.

A flood-gate or sluice which shuts out the ocean, as in docks opening to the sea, bears no more pressure than if it only stood against a lake or river; and if two immense flood-gates were placed so near to each other as only to enclose between them a few hogsheads of water, they would still be bearing as much pressure as if the Atlantic were resting on them.

Hence the fear is unfounded which many have expressed in speaking of the project of forming a canal between the Red Sea and the Mediterranean, that the first being twenty feet higher than the other, it might burst through the flood-gates, and carry devastation along its course.

A deep crevice in a rock filled by a shower, is often the cause of the rock being torn asunder, and of part being precipitated.

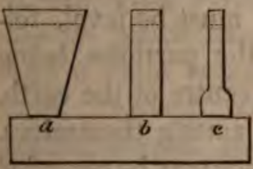
Extensive walls or faces of masonry, intended to confine banks of sand or earth, if no openings were left for water to escape from behind them, would be burst after rain, unless they had the strength of flood-gates of the same size. Ignorance of this danger has led to some extraordinary catastrophes.

Other examples of pressure in fluids being in all directions, and proportioned to the depth, are: the swelling and bursting of leaden pipes when filled from a very elevated source: the tearing up of the covering of a subterranean drain or water-course which has a considerable descent, when any accident choaks it near its lower opening, or when the flood is such as to fill it.—The violence with which water enters by an opening or leak near the keel of a deep-floating ship.—The great strength required in the hoops and securities of those casks used by porter brewers called vats, some of which contain many thousand barrels of liquid.

In speaking of the pressure of a fluid in all directions, some persons have difficulty in conceiving that there is an upward, as well as a downward and a lateral pressure. Now, if in a fluid mass, the particles below had not a tendency upwards proportioned to the pressure around them, from which they are trying to escape, they could not support the fluid above, which rests upon them. Again, if a long tube, open at both ends, and with a sliding plug or piston fitted to it, be partially plunged into water by the end to which the plug has been moved, it is found that the water presses the plug upwards with force proportioned to the depth to which it is carried, and exactly equal to the force with which it presses upon the bottom or side of a vessel at the same depth. On removing the plug altogether, the upward pressure is visibly proved and measured by the column of water which is pushed into the tube from below, and is there supported, to the level of the water around it.

The pressure in a mass of fluid, which is proportioned to the perpendicular depth, is not at all influenced by the size, shape, or position of the containing vessel.

A body immersed in the water of a lake, one foot under the surface, is just as much pressed upon, as if it were one foot under the surface of the sea, and no more than if it were one foot under the surface of a small cistern.



Suppose vessels differing from each other in form and capacity, as much as is sketched here at *a*, *b*, and *c*, but all having flat bottoms, of exactly the same area; if fluid be poured into all of them to the same level or perpendicular height, as represented here by the dotted lines, although the quantity will be very different in each, the pressure on the bottom will be the same in all. This truth is easily proved experimentally, by having the bottoms moveable, and held to their places by weights or springs capable of measuring the pressure.—This result is another exemplification of the two truths, *pressure equal in all directions* and *pressure as depth.* For as a column of the fluid resting on the middle of each bottom just presses with its whole weight, and therefore according to its altitude, this column could not remain at rest if there were any greater or less pressure than its own near it; and as the fluid is at rest in all the cases, and in all a central column is of the same height, the pressure must be equal on all the bottoms. This subject is illustrated by supposing the vessel *a* to be filled with upright rods of glass or pieces of smooth cane: it is evident that only those pieces which rested on the bottom, could press directly on it, while the others would be supported by the oblique sides of the vessel, and by the lateral resistance of the pieces around them.

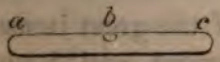
"*Level surface of a fluid*" (*read the analysis*).

That the surface of a fluid must be level, follows from the facts of all the particles being equally attracted towards the centre of the earth, and being perfectly moveable among themselves. The particles forming the surface may be regarded as the tops of so many columns of particles, supported by a uniform resistance or pressure below: and therefore a higher column must sink and a lower one must rise, until it be just balanced by those about it; that is, until all become alike. Besides this, just as a ball rolls down a slope or inclined plane, so do the particles of a fluid slide or move from any higher situation to any lower situation unoccupied near them.

A perfectly level surface on earth, really means one in which every particle is equidistant from the centre of the earth, and it is therefore truly a spherical surface; but so large is the sphere, that if a slice of it of two miles in diameter were cut off, and laid on a perfect plane, the centre of the slice would only be eight inches higher than the edges. Any small portion of it, therefore, for all common purposes, may be accounted a perfect plane.

So truly smooth does a fluid surface become, that it forms a perfect mirror; that is, it reflects or throws back the rays of light which fall upon it so exactly in the order which they had at leaving the object, that the eye receiving them, may fancy the object to be placed in the direction of the mirror.—It was over the glassy surface of the fountain or the lake, that the shepherdesses of the young world bent themselves, to learn the charms which nature had bestowed on them.—And a child contemplates with wonder and delight, through the window of a still pool or gliding stream, another sky appearing below the ground, with its clouds, and sun or stars; and another landscape, with inverted woods and mountains, the supposed dwelling of fairy beings.

In the cutting of canals, the making of railways, and in many other operations of engineering, it is of essential importance to determine the level or horizontal direction at any place; and this is best done by a tube of glass *a c*, filled with spirit except one bubble of air *b*, and called a spirit level. When this tube is horizontal, the bubble has no tendency to move to either end; but if the tube inclines ever so little, the bubble rises to the end which is highest. Such a tube properly fixed in a frame, with a telescope attached to it, or simply with sight-holes to look through, becomes the engineer's guide in many of his operations.



A hoop surrounding the earth would bend eight inches in every mile. In cutting a level canal, therefore, which becomes part of a hoop, it must appear to fall from the straight level line, found as now described, just in the said proportion.

Canals leading from seaports to the interior of countries have generally to ascend; but as water cannot become stagnant in any channel that is not level, the canal is divided by gates or sluices, into portions at different levels, like steps of a stair, the rise at the joinings being generally from six to twelve feet. The boat is raised or lowered from one level to another by the contrivance called a lock, which is merely a portion of the low level capacious enough for the boat to lie in, furnished with high walls, and with floodgates at both ends: so that when the gates below are shut, and water is gradually admitted from above, the lock becomes part of the high level, and as such it may deliver a boat, or receive one; and when the upper floodgates are shut, and the water as gradually allowed to escape from the lock, this becomes again part of the low level, and a boat may enter it or leave it by its lower gates.

The cutting of canals is one of the great items in the mass of modern improvement, and both marks and hastens the progess of civilization. Adverting to the importance of easy intercourse, as explained in a former section, we need only say here, that a horse draws one ton with difficulty on our best roads, but can draw thirty tons with the same speed in a canal boat.

And what a glorious triumph to science and art it is, to be able to conduct vessels of all kinds, even those originally intended for the ocean surge alone, through the quiet valleys of an interior country! In Scotland, at present, along the Caledonian canal, a noble frigate may be seen, wandering as it were, among the inland solitudes, and displaying her grace and majesty to the astonished gaze of the mountain shepherd; and having traversed the kingdom, and visited the lonely lakes, whose waters until now had only borne the skiff of the hunter, she descends again by the steps of the liquid stair, and safely resumes her usual place among the waves.

It is in contemplation at present to lead a ship canal across the isthmus which joins North and South America. The elevation to which the canal must reach to surmount the central ridge is considerable, and will increase the difficulty; but such important consequences would follow the accomplishment of the object, that with the continuance of general peace, and the increase of political wisdom, it will probably be attained. If so, the loaded vessel, rising from the Atlantic, would soon be descried among the mountain heights, and a little after would be safely delivered to a port of the opposite sea, having performed in a few hours, by a near cut, a voyage which at present costs months of delay and hazard, in a tedious navigation round the whole southern continent.

And if the Red Sea and Mediterranean were joined in the same way, as has also been proposed, it would, in effect, bring India near to Europe, and would more and more strengthen the bonds of mutual utility and brotherhood among the nations of the earth. Then, indeed, might it be said most truly, that the whole earth is a garden, which has been given to man as his abode, where every spot has its peculiar sweets and treasures; and the cultivator of each exchanging a share of what he produces for shares in return from others: the same general result follows, as if every field or farm contained within itself the climates and soils and capabilities of the whole earth.

In a canal, the least deviation from the true level would immediately cause any water admitted into it to flow towards the low end. This flux to a lower situation is what is going on in the myriads of streams, which render the face of the earth a scene of such varied beauty and incessant change.

As in the animal body, from even the minutest point, a little vein, endowed with living power, takes the blood which has just brought life and nutriment to the part, and delivers it into a larger vein, whence it passes into a larger still, until at last it meets the blood returned from every part of the body in the great reservoir of the heart: so in this terrestrial globe, where the magic moving power is simply fluid seeking its level, from every point of the surface, does the rain, which falls to sustain vegetable and animal life, and to renovate nature, glide into a lower bed, and from thence into a lower still, until the mingling streams, after every variety of combination, swell and constitute the great rivers which return again the accumulated waters into the common reservoir, the ocean. In the living body, the arteries carry back the blood with renewed vitality to every point whence the veins had withdrawn it, and so complete the circulation: and the circulation of the living universe is completed by the action of heat and of the atmosphere, which, from the extended face of the ocean, raise a constant exhalation of watery vapour of invisible purity, which the winds carry and deposit as rain or dew on every spot of the earth.

A very slight declivity suffices to give the running motion to water. One inch per mile, in a smooth straight channel, gives a velocity of about three miles per hour. The Ganges, which gathers the waters of the Himalaya mountains, the loftiest in the world, at eighteen hundred miles from its mouth, is only eight-hundred feet above the level of the sea—that is, about twice the height of St. Paul's Church in London; and to fall these eight hundred feet, it requires more than a month. The great river Magdalena, in South America, running for a thousand miles between the Andes on one side, and a ridge almost as lofty on the other, falls only five hundred feet in that distance. Above the commencement of the thousand miles, it is seen descending in rapids and cataracts from the mountains. The gigantic Rio de la Plata has so gentle an ascent from the ocean, that in Paraguay, at the distance of fifteen hundred miles from its mouth, large ships are seen which have sailed against the current all the way, by the force of the wind alone.

If a small lake or extensive mill-pond, with very uneven bottom, were suddenly emptied by a sluice or opening in its lowest part, a vast number of pits or pools of various size and shape would be left among the inequalities of the bottom. But supposing rain to continue falling, or frequently to recur, a remarkable change would soon by effected; each pool by running over at its lowest part, and sending out a streamlet either into another lower pool, or into a channel leading directly to the sluice or opening, would be wearing away the part or side over which the water were running, so that the breach or channel would become gradually deeper, and the water in the pool would consequently become shallower; while at the same time the bottom would be filling up with the sand or mud washed down by the rain from the elevations around: and these two operations being continued, the pool would at last disappear altogether. This operation going on in every pool through the whole of the emptied mill-pond, the bottom would at last exhibit only a varied and undulated surface of dry land, with a beautiful arrangement of ramifying channels, all sloping with a precision unattainable by art, to the general mouth or estuary. The reason that in the supposed case, and in every other, a water-course soon becomes so singularly uniform as to dimension and descent, is, that any pits or hollows in it are soon filled up by the sand and mud carried along in the stream, and deposited where the current is slack; while any elevations are worn away by the action of the more rapid current which accompanies shallowness, until throughout the whole line only a uniform and gradual slope remains.

The above paragraph, describes in miniature, what has been going on over the general face of our earth, ever since that convulsion of nature which produced its present form. In many places the phenomenon is already complete; in others it is only in progress. The whole of what is now dry land, has at some period been under water, and much of it has evidently been a gradual deposition from water. By some extraordinary convulsion, therefore, our present continents and islands must have been thrown up from the bottom of an ocean, or an ocean must have subsided away from them; and in either case the earth must have risen as checquered and unsightly, as the bottom of the lake supposed above, when first emptied. And it is the gradual operation of *water seeking its level*, which has gradually converted it into the paradise which we now behold.

The marks of the former state of the world, and of the progressive change, are every where most strikingly evident to the enlightened eye of philosophy. The present kingdom of Bohemia, for instance, is the bottom of one of the great lakes which once covered Europe. It is a basin or amphitheatre, formed by circular ridges of mountains, and the only gate or opening to it, is that remarkable one by which the water escapes from it, and which has evidently been gradually cut or formed by the action of a running stream. As the bottom became uncovered by the sinking of the water, and by the formation of a regular sloping channel from every part, the former lake was converted into a fine and fertile country, a fit habitation for man; and the continued drain from it is the beautiful river which we now call the Elbe.

In Switzerland, even now many of the vallies which were formerly lakes, have the opening for the exit of water so narrow, that, as happened in one of them a few years ago, a mass of snow or ice falling into it, converts the valley once more into a lake. On the occasion alluded to, the accumulation of water within was very rapid; and although, from the danger foreseen to the country below if the impediment should suddenly give way, every means was tried to remove it gradually, the attempt had not succeeded when the frightful burst took place, and involved all below in common ruin.

The magnificent Danube is the drain of a chain of basins or lakes, which must at one time have discharged or run over one into another, but the continued stream cutting a passage at last low enough to empty them all, they are now regions of fertility, occupied by civilized man, instead of the fishes which held them formerly. This operation is still going on in all the lakes of the earth. The lake of Geneva, for instance, although confined by granite rock, is cutting and lowering its outlet, and the surface has fallen considerably within the period of accurate observation and records; and the wearings of the neighbouring mountains, brought down by the winter torrents, are filling up its bed. If the town of Geneva last long enough, its inhabitants will have to speak of the river in the neighbouring valley, instead of the picturesque lake which now fills it. Already several other towns and villages, which were close upon the lake a century ago, have fields and gardens appearing between them and the shore.

It is very interesting to observe and account for the contrast between the pure blue water of the Rhone issuing from the lake of Geneva, and the turbid streams which join its course a little farther down. The torrents which fall into the lake all around, are generally charged with the debris or wearings of the mountains; but in the still bosom of the lake they deposit all their load, and the pure water alone escapes to form the river. On the other hand, the streams coming to the Rhone directly from the Alps, bring their charge of broken-down earth with them; and even after they have joined it, they are long distinguishable by their muddy waters. It is the mud deposited in the way described which is gradually filling up this and other lakes, and which has formed the vast regions of flat country found about the mouths of most great rivers.

The immense continent of Australasia, or New Holland (larger than Europe), is supposed by some to have been formed at a different time from what is called the old world; so different and peculiar are many of its animal and vegetable prodirections; and the idea of a later formation receives some countenance, from the immense tracts of marshy or imperfectly drained land which have been discovered in the interior, into which rivers flow, but which seem not yet to have worn down or formed a sufficient outlet or discharging channel towards the ocean.

Where the soil or country through which a water-track passes is not of a soft consistence, to allow readily this natural filling up of hollows by deposited sand, and the wearing down of higher parts, lakes and great irregularities of current remain. There are, for instance, the line of lakes in North America, the rapids of the St. Lawrence; and the stupendous falls of Niagara, where, at one leap, the river gains a level lower by one hundred and sixty feet. A softer barrier than the rock over which the river pours in these places, would soon be cut through, and the line of lakes would be emptied.

The contemplation of the fact, that water in seeking its level is constantly wearing where it rubs, and carrying the abraded portions down to lower levels, and ultimately to the bed of the ocean, brings irresistibly the awful idea, that this earthly abode of ours can have but a limited existence in its present state, owing to natural causes already in operation. No shower falls that does not send some portion of mountain or plain into the depths of the ocean, and thus cause a corresponding encroachment by the rising water; and with revolving ages, unless new convulsions of nature disturb the progress, or art succeed, as in Holland,

and near the mouths of some other great rivers, to shut out the ocean from extensive low tracks by means of sea dykes or embankments, the dry land must at last disappear, and another gradual but general deluge must embrace the globe.

There is, perhaps, nothing which illustrates in a more striking manner the exact accordance of nature's phenomena with the few general expressions or laws which describe them all, than the perfect level of the ocean and of all liquid surfaces. The sea never rises or falls in any place, even one inch, but in obedience to these laws, and therefore changes may generally be foreseen and allowed for. For instance, the eastern trade-winds and other causes force the water of the ocean towards the African coast, so as to keep the Red Sea about twenty feet above the general ocean level; and the Mediterranean Sea is a little below that level, because the evaporation from it is greater than the supply of its rivers, and it is therefore receiving a constant supply by the Strait of Gibraltar: but in all such cases of exception to the general law, the effect is as constant as the disturbing cause, and therefore can be calculated upon with equal confidence.

Were it not for this perfect exactness, in what a precarious state would the inhabitants of the sea-shores and of the banks of low rivers exist! Few of the inhabitants of London, perhaps, reflect when standing close by their river side, and gazing on the rapid flood-tide pouring inland through their bridges, that although sixty miles from the sea, they are placed as low as those sailing upon its face, which perhaps at the time may be lifted in tossing waves, and covered with wrecks and the drowning.

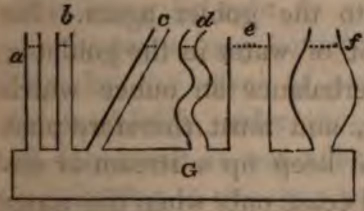
The horrible destruction that would follow any alteration in the level of the ocean, may be judged of by the effects of occasional floods, whether produced by rains and melting snow in the interior of countries, or by these combined with the effect of winds and high tides on the coast. The flood at St. Petersburgh, in 1825, was dreadful, in which strong westerly winds had retarded the flow of the river so much that the water rose forty feet above its usual mark, covered all the low parts of the town, and destroyed thousands of human beings.

In Holland, which is a low flat, formed chiefly by the mud and sand brought down by the Rhine and other neighbouring rivers, much of the country is really below the level of the common spring tides, and is only protected from constant inundations by artificial dykes or ramparts, made strong enough to resist the ocean. What awful uncertainty would hang over the existence of the Dutch, if the level of the sea were subject to change: for while we know the water of the ocean to be seventeen miles higher at the equator than at the poles, owing to the centrifugal force of the earth's rotation; were the level, as now established, from any cause to be suddenly changed but ten feet, millions of human beings would be the immediate victims.

Where the inundation is regularly periodical, as in the Nile, the hurtful effects can be guarded against, and the event even becomes useful by fertilizing the soil.

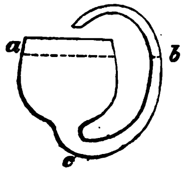
Tracts of land situated in contact with rivers, and between the levels of ebb and flood tide, may be kept constantly covered with water, by surrounding them with dykes, and opening the sluices at high water only; or they may be kept constantly drained by opening the sluices only at low water. Immense extent of rice fields near the mouths of rivers in India and China, are managed in this way, the admission or exclusion of water depending on the age of the rice plant.

“ *If various tubes and vessels communicate with each other, fluid admitted to them will rise to the same level in all.*” *(Read the analysis, p. 226.)*

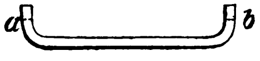


The adjoining sketch may represent a variety of tubes and vessels, fixed upon and all opening to the box G. Water poured into any one would fill the box, and would then rise to the same level in all. The dotted lines from *a* to *f*, may represent the surfaces of the fluid in the different vessels. In the figure at page 229, it was seen why in all upright cylindrical vessels, as *a b e*, the fluid rises to the same level, and the figure at p. 239, explained why shape or inclination of vessel cannot affect the level. Although in the vessel *c*, there is more water than in *a*, still there is the same pressure at the bottom of both, because *c* supports part of the weight of its contained fluid on the principle of the inclined plane.

If a tube twenty miles long, and rising and descending among the inequalities of a country, were filled with water, and could then have its ends brought together for comparison, it would exhibit two surfaces having precisely the same level, and either end being raised, the fluid would run over at the other.



A projector thought that the vessel of his contrivance, represented here, was to solve the renowned problem of the perpetual motion. The vessel *a* is goblet-shaped, lessening gradually downwards until it becomes a tube, which is then bent upwards at *c*, and points with an open extremity into the goblet again. He reasoned thus: A pint of water in the goblet *a*, must more than counterbalance an ounce which the tube *b* will contain, and must therefore push the ounce forward, and keep up a stream or circulation: and this will cease only when the water dries up. He was counfounded when a trial shewed him the same level in *a* and in *b*.



An easy mode of determining a level line at any spot is to have an open tube, bent up at its ends, and nearly filled with some fluid: by then looking along the two surfaces, an observer looks in a line quite horizontal.

If there were two lakes on adjoining hills of different heights, a pipe of communication descending across the valley, would soon bring them to the same level; or if one were much lower than the other, it would empty the one into the other.

A glass tube inserted into the bottom of an open cask or cistern of any sort, and then bent upwards, and appearing on the outside like a barometer tube, shews by the elevation of the fluid in it, the height of the liquid within.

In like manner a tube brought from a river into a neighbouring cellar or pit, indicates the height of the water in the river.

A knowledge of the truth, that water in pipes will always rise again to the height or level of its source, has enabled us in modern times to construct those admirable systems of iron pipes, which distribute water in our great towns. The water being brought to any elevated site in or near the town, may be delivered from a reservoir there, by the effect of gravity alone, to every cistern which is under the level of the reservoir, and the result is not affected by the conveying pipes having to rise over heights and to descend into vallies many times in their course.

On the hill north of London, on which Pentonville stands, there is a reservoir to which water is brought from Hertfordshire, by a channel cut for the purpose upwards of thirty miles in length, and called the New River. Another reservoir has been very lately constructed near Primrose Hill, by the West Middlesex Water Company; it is higher than any house in town. It is filled by the operation of steam engines at the company's works at Hammersmith, five miles off. It will supply water to the summits of all the houses connected with it, and may be exceedingly useful in cases of fire.

Many have believed that the ancients were ignorant of the law, that fluid in pipes will rise to the level of its source, because in all the ruins of their aqueducts, the channel is a regular slope. Some of these aqueducts as works of magnitude, are inferior only to the great wall of China, or the Egyptian Pyramids; yet at the present day, a single pipe of cast-iron is made to answer the same purpose just as perfectly. It is now ascertained, however, that it was not ignorance of the principle, but want of fit material for making the pipes, which cost our forefathers such enormous labour.

The supply and distribution of water in a large city, since the steam engine was added to the apparatus, approaches closely to the perfection of nature's own work in the circulation of blood through the animal body. From a general reservoir a few main pipes issue to the chief divisions of the town; these send suitable branches to every street, and the branches again divide for the lanes and alleys; while at last into every house a small leaden conduit rises, and if required, carries its precious freight into every apartment, where it yields it to the turning of a cock. A corresponding arrangement of drains and sewers, constructed with the greatest exactness in obedience to the law of level, carries the water away again when it has answered its purposes, and sends it to be purified in the great laboratory of the ocean. And so admirably complete and perfect is this counter system of sloping channels, that within the space of an hour, a heavy shower may fall, and after washing and purifying every superficial spot of the city, and sweeping completely all the subterranean passages, it may again be collected in the river passing by. It is the recurrence of this almost miracle, of extensive, sudden, and perfect purification, which has made London the most healthy, although the largest city in the world.

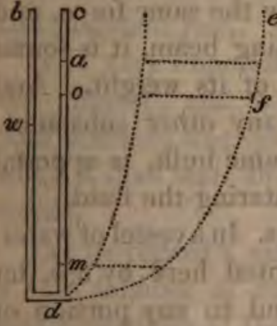
English citizens have now become so habituated to the blessing of a supply of pure water more than sufficient for all their purposes, that it causes them no more surprise than the regularly returning light of day or warmth of summer. But a retrospect into past times awakes us to a sense of our obligation to advancing art. How often have periodical pestilences arisen from deficiency of water, and accumulation of impurities; and how often have whole cities been devoured by fire, which a timely supply of water might have saved; and kings have been accounted worthy of almost divine honours for having constructed an aqueduct to lead the pure stream from the mountain to the peopled towns, &c. In the present day, he who has travelled on the sandy plains of Asia or Africa, where a well is more prized than mines of gold—or he who has spent months on ship-board, where the fresh water is often doled out with more caution than the most precious product of the still—only he can appreciate fully the blessing of that abundant supply which most of us now so thoughtlessly enjoy.

The subject of *fluid level* leads to the consideration of springs or wells, and the operation of boring for water.

The water which falls from the clouds may either find its way directly to the rivers, by running along the surface of a soil that refuses it admittance; or it may sink into loose porous earth, and again ooze from it in some lower situation in the form of a spring. If a hole or pit be dug in such earth, to below the level of the water lying in it, the pit will soon fill with water up to such level, and will be called a well. Sometimes the level of the subterranean water is very low, and in many places there is none within an accessible distance, by reason of there being an easy drainage towards the sea, or of the soil being altogether impermeable to water.

The surface of our globe is formed of different strata or layers, as of clay, chalk, sand, &c. &c., which appear all to have been at some former period horizontal, and probably under water, and to have been afterwards thrown up, by some convulsion of nature, in every variety of state. In particular situations, the upper surface is of basin shape, and then the strata or layers are as cups or basins placed one within another; and as water poured in between two porcelain basins so placed, until it reaches their lips, would spring out by any hole made through the side of either, so in boring for water through the innermost water-tight stratum or basin of earth, the water springs out and rises to the surface. London stands in a basin of clay placed over chalk, and on boring through the clay (sometimes of three hundred feet thickness), the water issues, and will often rise considerably above the surface of the ground, shewing that there is a much higher source or level somewhere—probably among the Surrey hills and those north of London.

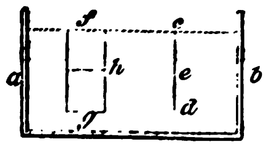
When fluids of different kinds, and of different weights under the same bulk, are made to act against each other in communicating vessels—as water, for instance, in one leg of the bent tube *b d c*, and oil in the other, the surfaces will not be at the same height or level, but that of the lighter fluid will be just as much higher than that of the other as it is lighter. Thus the column of oil must be of a length as *o d*, to balance the column of water *w d*. And to balance the same water, alcohol, because lighter than oil, would have to stand higher still, as at *a*; and mercury, because thirteen times weightier than water, would stand only at *m*. The shape, size, or position of the vessels in which the opposing fluids might stand, would have no influence on the relative height of the surfaces; and if we suppose a larger vessel, such as represented by the dotted lines here, to replace the leg *c d* of the tube, the various fluids to balance the water in *b d*, would have to stand just as high in it as in the smaller tube *c d*.



"*A body immersed in a fluid displaces exactly its own bulk of it; and as this bulk was just supported by the fluid around, the body is held up by the force which sustained the fluid, and it must sink or swim according as it is heavier or lighter than its bulk of fluid.*"

A bladder full of air, and having the bulk of a pound of water, requires force of one pound (except a grain or two, the weight of the air) to plunge it under water. The same bulk of gold is held up in water with exactly the same force, and if suspended from a weighing beam, it is found then to have lost one pound of its weight. And a piece of wood, ivory, or any other substance, provided it has exactly the same bulk, is opposed by the same resistance on entering the fluid.

The reason of this is obvious. In a vessel of water, represented here by *a b*, let us attend to any portion of the water, such as a single column of particles represented by the line *c d*: we know that such column is steadily supported in its place, because the surface of the liquid immediately under it is tending upwards to escape from the surrounding pressures, with force exactly equal to its weight; and what is true of a column of single particles, is true of any other portion, such as the larger column represented by the figure *f h g*. If such portion weighed exactly a pound, the surface under it would be tending upwards with the force of a pound; and if the por-



tion were to become ice, without changing its bulk or form, it would still be exactly supported by the surface below pressing upwards with force of a pound; and if the column were of wood, stone, or metal, the surrounding pressures would be in no degree different. Again, if we suppose only half the column to be solidified in the position *h g*, it would still be pressed upwards with a force of one pound at *g*; but its own weight of half a pound, and the weight of the half pound of water above it, would produce an exact balance and maintain rest.

It is very important to have clear notions on this subject; and as different minds apprehend with different degrees of facility, and in different ways, I shall state the same general truth in other words.

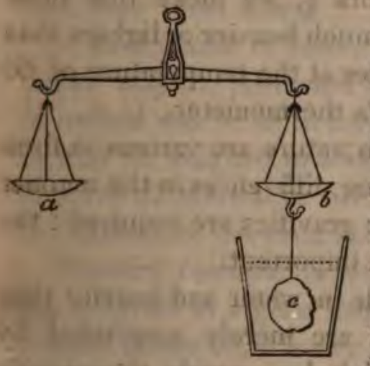
Let us regard a mass of fluid, as consisting of a vast number of extremely minute columns of single particles of the fluid, standing side by side, and every particle supporting those above it by the tendency upwards, which it has through the pressure of the surrounding fluid down to its level. Now if we suppose the particles of any portion of the fluid mass, of any shape, to stick together or to become ice without changing their bulk or weight, that portion when solid would still be between the same forces as when fluid, and therefore would be equally supported, and would remain at rest. And if gold, or silver, or glass, or wood, having the same bulk, were substituted for the supposed ice, such new substance would still be sustained with the same force; so that if it were of exactly the same weight as the ice or water displaced, it would have no tendency either to rise or to fall, more than the water itself had; but if it were heavier it would sink, and if lighter it would swim, and in either case with force exactly proportioned to the difference between its weight and that of an equal bulk of water.

Few persons, in reading for the first time the statement of this simple and now obvious truth, would imagine that it expresses one of the most important discoveries which human sagacity has fallen upon. It was made by one of the master minds of antiquity—that of Archimedes, while his limbs were resting on the liquid support of a bath; and as his godlike intellect darted into futurity, and perceived many of the important uses to which the knowledge was applicable, he is said to have become so wrapt in admiration and delight, that he leapt from the water, and, unconscious of his nakedness, pursued his way homewards, calling out "ευρηκα, ευρηκα," I have found it. He was thinking chiefly of the ready means, hence obtained, of ascertaining in all cases what has since been called the *specific gravity* of bodies, *viz.* the comparative weights of the same bulk of different substances, as of gold compared with silver, or copper, or iron, &c.; and in the case of mixtures, as of gold with silver for instance, of saying at once what proportion is present of each—a problem which, until then, there was no correct means of solving.

The hydrostatic law now explained, has since become a chief foundation of chemistry, and cause of improvements in navigation, in marine architecture, and in many other arts. By it the chemist distinguishes one substance from another, a pure substance from an impure one, and the nature of mixtures or compounds; the merchant often judges by it of the worth of his merchandize; and in any case it enables an inquirer to ascertain at once the exact size or solid bulk of a mass, however irregular.

We shall now discuss more particularly the subject of *comparative weights* or *specific gravities*.

" *The force with which a body is held up in a fluid being the exact weight of its bulk of that fluid, by comparing this with the weight of the body itself, the comparative weights or* SPECIFIC GRAVITIES *are found.*" (*Read the analysis, page* 226.)



If any body *c*, a mass of gold for instance, be suspended by a thread or hair from the bottom of one scale *b* of a weighing beam, and be then balanced by weights put into the other scale *a*, and if a vessel of water be then lifted under it so that the water shall surround it, the body is pushed up or supported by the water with force equal to the weight of the water which it displaces; the weight, therefore, now required in the scale *b* to restore the balance, is truly the exact weight of the water displaced; or of water equal in bulk to the body; and the weights in the two opposite scales shew the comparative weights of a given bulk of gold and of water. Suppose the piece of gold in the present case to weigh in the air $19\frac{3}{10}$ ounces, or pounds, or grains, it would lose, when the water surrounded it, one ounce, or pound or grain, that is, the water would support it with this force, and therefore gold would be proved $19\frac{3}{10}$ times as heavy as water.

It was necessary to select a common standard with which all other things should be compared, and this has been done in choosing water; the reasons of preference being, that water can be so easily procured in a state of purity, and therefore of uniformity, in all situations. When we say, therefore, that gold is of the specific gravity 19, and copper 10, and cork $\frac{1}{4}$, we mean that these substances are just so much heavier or lighter than their bulk of pure water at the temperature of 60 degrees of Fahrenheit's thermometer.

As the substances in nature are various in form and kind, corresponding differences in the manner of ascertaining specific gravities are required: the following are the most important.

Solid bodies insoluble in water and heavier than it, as the metals, &c. are merely suspended by thread or a hair which has nearly the specific gravity of water to one scale of the hydrostatic balance (this may be described simply as a weighing beam furnished with a water vessel below it) and the body being first balanced or weighed in the air, and then in water as already described, the weights in the opposite scales are the weights of equal bulks of the two substances; and by finding, through the arithmetical operation of *division*, how often the weight of the water is contained in the weight of the solid, we find the specific gravity of the solid, or how much it is weightier than its bulk of water.—It is almost superfluous to remark, that putting weights into the scale *b*, or taking them out of the scale *a*, are equivalent operations.

Solids lighter than water, as cork, are weighed in it, by attaching to them a mass of metal or glass, already balanced in water for the purpose, which may cause them to sink; or by making the line which connects them with the weighing beam pass under a small fixed pulley at the bottom of the vessel, so that the rising of the end of the beam may draw them down.

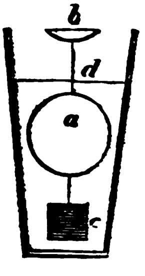
A solid soluble in water, as a crystal of any salt, either may be protected by previously dipping it in melted wax so as to leave a thin covering on it, or may be weighed in some liquid which does not dissolve it, allowance being made afterwards for the difference between such liquid and water.

Powders insoluble in water, such as gold-dust, are weighed in a glass cup, which has been previously balanced in water for its purpose.

Powders soluble in water must be weighed in some other liquid. Mr. Leslie, the highly endowed professor of natural philosophy in the university of Edinburgh, has lately suggested a novel and most ingenious mode of ascertaining the specific gravities of pulverized or porous bodies; but it can only be understood by persons acquainted with the doctrines of pneumatics, and the consideration of it must therefore be delayed.

Other liquids may be compared with water, as to their weight, in several ways.

1st. If a phial be made to hold exactly one thousand grains of water, the weight of the same measure of any other liquid is found, by simply filling the phial and weighing it. Of sulphuric acid, for instance, such a phial will contain nearly nineteen hundred grains, while of alcohol it will receive only about eight hundred. 2d. A bulb of glass, which loses one thousand grains when weighed in water (which thousand grains is therefore the weight of its bulk of water), may be weighed in other liquids, and the difference of loss gives the specific gravity, as in the last case.—The bulb may be of any size, but one which loses exactly one thousand grains is preferable, from the simplicity thereby given to the calculations. The same remark applies to the phial last mentioned. 3d. A contrivance which renders the beam and scales altogether unnecessary, is a hollow bulb of glass or metal *a*, with a slender stalk rising from it, and supporting the little scale or dish *b*, and with another stalk descending to carry the weight or weights at *c*, which serve as ballast, to it when floating. The whole is adjusted to float in pure water, so



that a certain mark upon the upper stalk, shall be at the surface of the water. By then immersing it in other liquids, and by finding how much weight must be added to it in the little scale above, or taken from its load below, to make it float at the same elevation, the comparative weights of these other liquids and of water are found; or the difference of weight which makes it float at different elevations, having been previously ascertained, it will only be necessary to note exactly the elevation. This instrument is called an *hydrometer*. There are generally printed tables and directions accompanying all forms of it, to tell the exact import of the several indications for different liquids, and the allowances required for temperature, &c. 4th. The shortest mode of ascertaining the specific gravity of liquids, is to have small glass bubbles, forming a set or series of different specific gravities, so that when thrown into any liquid, those heavier than it will sink, and those lighter will swim, and that one which marks its specific gravity will just be suspended. The individuals of the series must of course be numbered, and the specific gravity of each known.

A common use of hydrometers is to ascertain the quality of the distilled spirits brought to market, as rum, brandy, gin, &c. All these consist of alcohol more or less diluted with water, and duty or tax is paid upon them in proportion to the strength, or the quantity of alcohol which they contain. A delicate hydrometer discovers this at once with the greatest exactness.

A shopkeeper in China sold to the purser of a ship, a quantity of distilled spirit according to a sample shewn; but, not standing in awe of conscience, he afterwards, in the privacy of his storehouse, added a certain quantity of water to each cask. The article having been delivered on board, and tried by the hydrometer, was discovered to be wanting in strength. When the vender was first charged with the intended fraud, he denied it; but on the exact quantity of water which had been mixed being specified, he was confounded, for he knew of no human means which could have made the discovery, and he confessed his roguery, and made ample amends. When the instrument was afterwards shewn to him, he offered any price for what he foresaw might be turned to good account in his trade.

The specific gravity of *aeriform substances* is ascertained by means of a glass flask of known size, with a stop-cock. This is first weighed when emptied by the air-pump, and afterwards when filled successively with water and with the different airs or gases. Comparison of the weights gives the specific gravities as already described.

The following table shews in round numbers the comparative weights or specific gravities of some common substances. Water is the standard kept in view, and any equal bulk of the other substances is heavier or lighter than water according to the numbers severally attached to them.

Platinum	$22\frac{1}{2}$	Common Salt	2
Gold	$19\frac{1}{3}$	Brick	2
Mercury	$13\frac{1}{2}$	Alcohol	$\frac{8}{10}$
Copper	$8\frac{3}{4}$	Æther	$\frac{3}{4}$
Steel and Iron	8	Cork	$\frac{1}{4}$
Diamond	$3\frac{1}{2}$	Atmospheric Air	$\frac{1}{800}$
Glass	3	Hydrogen Gas	$\frac{1}{18000}$
Common Stones	$2\frac{1}{2}$		

Complete tables are found in Systems or Dictionaries of Chemistry.

A cubic foot of water happens to weigh one thousand ounces avoirdupois. Hence in the foregoing table the figures denoting the specific gravities, tell how many thousand ounces of the different substances a cubic foot contains. Gold, for instance, nineteen thousand; common air only little more than one ounce; and hydrogen gas, the lightest of ponderable things, less than a drachm.

The following facts are further illustrations of the truth that a body immersed in a fluid, is held up or resisted with force equal to the weight of the quantity of fluid which it displaces.

A stone which on land requires the strength of two men to lift it, may be lifted in water by one man. There are cases where the support of water obtained in this way is equivalent to the assistance of an additional hand.

The invention of the diving bell in modern times, having enabled men in the building of piers, bridges, &c. to work under water almost as freely as above its surface, it always surprises workmen at first, to find that they can move much larger and heavier stones down below than in the air. In recovering property from a sunken ship by the diving bell, every thing is found to be lighter in the proportion just stated.

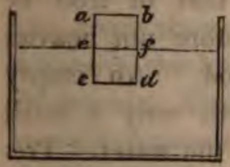
This law explains also why stones, gravel, and sand, are so easily moved by waves and currents. Many people expressed astonishment in March 1825, on learning that at the Plymouth Breakwater, the storm had displaced blocks of stone, of many tons weight; but we now see that the moving water had only to overcome about half the weight of the stone.

When a person lies in a bath extended horizontally, the limbs are very nearly supported by the water without any exertion on the part of the individual. If this softest of all beds be indulged in for half an hour or more, on first lifting a limb out of the water the party feels surprise at its great apparent weight. The workers about diving bells always experience the sensation now spoken of on returning to the air.

The bodies of most fishes are nearly of the specific gravity of water, and therefore if inactive they sink or rise very slowly. When this subject was less understood, it was commonly said that fishes had no weight in their own element, and it is related as a joke at the expense of philosophers, that when a king once proposed it as a question to his men of science, to explain this extraordinary fact, many profound disquisitions came forth, but not one of the competitors thought of trying whether it really was a fact. At last some simple man balanced a vessel of water in scales, and when he put a fish into it, the scale preponderated just as much as if the fish had been weighed alone.

In the sense now explained, water is said to have no weight in water. The least force will raise a bucket of water from the bottom of a well to the surface of it; but if the bucket be lifted at all farther, the weight is felt, and just in proportion to the part of it which is above the surface.

"*A body lighter than its bulk of water will float, and with force proportioned to the difference.*" (*Read the analysis, p.* 226.)



The reason of this is clear. If any body, the cylinder *a, b, c, d,* for instance, be partially immersed in water, we know that the upward pressure of the water on the bottom *c d,* is exactly what would support the water displaced by the body, *viz.* water of the bulk, *e f c d.* The body therefore, that it may remain in the position here represented, or that it may float, must have exactly the weight of the water which it displaces; and if it be lighter than this, a proportionate part will be above the liquid surface, if heavier it must sink altogether.

Hence a pound weight of any body which floats in water, displaces the very same quantity of water, whether that body be very light, as cork, or heavier, as a piece of dense wood. This is experimentally shewn by putting such bodies to float in a vessel which was quite full of water. The water displaced by each must run over the sides of the vessel, and may be caught and measured.

A body when floating in water, then, is pushed up until only so much of it remains in the water as to occupy the place of a quantity equal in weight to itself; hence,

A porcelain basin of four ounces, will sink in water only as far as a wooden bowl of the same weight; and the weight of the bowl may either be in the wood itself, or in any thing else put into it as a load.

Hence a boat of iron floats just as high out of water as a boat of wood, if that of iron be thinner in substance, and therefore not heavier upon the whole, than the wood. An empty metal pot or kettle floats, with only a small part of it below the surface of the water.—Prejudice for a long time prevented iron boats from being used, although they are superior to others for various purposes; and there are many people still who would fear to go on board of a ship built of the strong and almost everlasting Indian teak-wood, because it is heavier than water, and in the form of a log, therefore, sinks in the water. Many fine ships of the line, and great East-Indiamen of fifteen-hundred tons, are now built of teak.

Hence a ship of one thousand tons will just draw the same water, or float to the same depth, whatever her cargo be, if of equal weight. And the exact weight of a ship and her cargo is determined when it is known how much water she displaces. In canal boats, which are generally of a simple form, this truth affords a rule for ascertaining the quantity of their load.

The human body, in an ordinary healthy state, with the chest full of air, is lighter than water.

If this truth were generally known and well understood, it would save more lives, in cases of shipwreck and other accidents, than all the mechanical life-preservers which man's ingenuity will ever contrive.

The human body is so much lighter than water, that it naturally floats with a bulk of about half the head above the water; and if the person is tranquil, the body can no more sink than a log of fir would. That he may live and breathe, then, it is only necessary that he exert his volition to render the face that part which is to remain out of the water.

The reasons that so many people are drowned in ordinary cases, and who might be so easily saved, are the following:

1st. Their not knowing that the body is really lighter than water.

2d. Their believing that continued exertion is necessary to keep the body from sinking; hence the position of a swimming man is generally assumed, in which the face is downwards, and the whole head must be kept out of the water to allow of breathing. Now as a man cannot retain this position without continued exertion—even if a swimmer he is soon exhausted, and if not, the unskilful attempt will scarcely secure for him even a few respirations.—A body raised for a moment above the natural level by exertion, sinks as far below when the exertion ceases: the plunge terrifies the unpractised individual, by appearing to be the commencement of a permanent sinking, and fear soon makes him an easy victim to his fate.

3d. The fear that water entering by the ears may drown, as if it entered by the nose or mouth: the truth being, that it can only fill the outer ear as far as the membrane of the drum, and is therefore of no conequence. Every diver and swimmer has his ears constantly filled with water, and with impunity.

4th. Persons unaccustomed to the water, and in danger of drowning, in their struggle generally attempt to keep their hands above the surface, from feeling as if their hands were tied while below; but this act is most pernicious, because any part of the body kept out of the water, in addition to the face which must remain above, requires effort to support it, which the individual is supposed incompetent to afford.

5th. Not having reflected, that when a log of wood or a human body is floating upright, with only a small portion above the surface, in rough water, as at sea, every wave must cover the head for a little time as it passes, but will again leave it projecting in the interval. The practised swimmer chooses this interval for breathing.

6th. Not knowing the importance of keeping the chest as full of air as possible, the doing which has the same effect as tying a bladder of air to the neck, and without other effort will cause nearly the whole head to float above the water. If the chest be once emptied, and if from the face being under water the person cannot inhale again, the body is then specifically heavier than water, and will sink.

When a man dives far, the pressure of deep water compresses or diminishes the bulk of the air in his chest, and hence he becomes really heavier than water, and would not again rise, but for the exertion of swimming. The author once saw a sailor (a fine-bodied West-Indian negro) fall into the calm sea from a yard-arm eighty feet high. The velocity was so great, that he shot deep into the water immediately, and, of course, his chest was compressed as now explained; probably also the shock stunned him, for although he was an excellent swimmer, he only moved his arms feebly once or twice, and was then seen gradually sinking for a long time afterwards, until he disappeared, as a black and distant speck, descending to the unknown regions of the abyss.

It is not, perhaps, to be recommended, that every person should learn to swim; but every one should have practised the easy lesson of resting in the water with the face out. A little action of adjustment with the hands makes it a very easy position: and there is an accompanying motion of the feet, called *treading the water*, which is easily learned, and which sustains the entire head above the surface. Perhaps the whole of the seventy passengers who were swallowed up on the sudden sinking of the Comet steam-boat near Greenock, in October 1825, might have been saved, had they known the truth which we are now explaining, as boats so soon came to their assistance.

In having to swim very far, a man may thus rest on his back for a time, and resume his labour when he is somewhat refreshed.

So little is required to keep a man's whole head above water, that many individuals, altogether unacquainted with what regards swimming or floating, have been saved after shipwreck, by catching hold of a few floating chips or broken pieces of wood; an oar will suffice as a support to half a dozen people, if no one of the number attempts to keep more than his head out of the water.

A common life-preserver consists of strings of corks put round the chest or neck; or of an air-tight bag applied round the upper part of the body, and which can be filled by the person blowing into it through a valved pipe attached.

On the great rivers of China, where thousands of people find it more convenient to live in covered boats upon the water, than in houses on shore, the younger male children have a hollow ball of wood or other material attached constantly to their necks, and in their frequent falls overboard are not in danger.

Life-boats have a large quantity of cork mixed in their construction; or of air-tight vessels of copper and tin plate, so that, even if full of water, they shall still float high above its surface.

Swimming is much easier to quadrupeds than to man, because the common motion of their legs in walking and running is that which best supports them in swimming. Man is the most helpless of creatures in water. A horse can carry his rider with half the body out of the water; dogs that have never been in water before swim well on the first trial. Swans, geese, and water-fowls in general, are so bulky and light, by the great thickness of feathers under them, that they float upon the water like stately ships, and their webbed feet are perfect oars.

A man may walk upon broken glass with impunity in deep water, because his weight is supported by the water.

But many men have been drowned in attempting to wade across the fords of rivers, from forgetting that the body is supported by the water, and does not press on the bottom sufficiently to give a sure footing against a very trifling current. A man, therefore, carrying a weight on his head or shoulders, may safely pass in such a case, where, without a load, he would be carried down the stream, and would perish.

Fishes can change their specific gravity, by diminishing or increasing the size of a little air bag within their body; and which being towards the under side, causes a dead fish to float with the belly uppermost.

Animal matter, in undergoing the process of

ction, forms much aeriform substance.
e the bodies of drowned persons generally
after a time, and rise, and again sink when
ir has burst the parts containing it.

e pressure or resistance of a fluid being as the
depth, and uninfluenced by the shape of the
vessel or the quantity of the fluid, a body floats
to the same depth in a small pond, in a lake,
or in the sea.

A porcelain basin floats in water to the same depth, whether it be placed in a large vessel, or in another basin so little larger than itself, that a spoonful or two of water may suffice to fill the interval between them. One ounce of water in this way may float a thing of a pound weight; and if the largest ship of war ready for sea were received into a dock, or case, which so exactly fitted her that there were only half an inch of interval between her and the wall all round, she would float as completely when the few hogsheads of water required to fill this little interval up to her usual water-mark were poured in, as if she were on the high sea. In some canal locks, the boats just fill the space in which they have to rise and fall, and thus the expense of water at the lock is diminished.

A floating body, to be stable in its position, mu
have its centre of gravity below the centre
gravity of the fluid which it displaces; and
cording as this is so, and as the bearing is br
the degree of stability is great.

Hence arises, in the stowing of a ship's cargo, the necessity of putting the heavy merchandise underneath, and generally of putting iron ballast under all the merchandise. Hence, also, the danger of having a cargo or ballast which may shift its place. A ship loaded with stones only is sometimes lost by a wave making her incline for a moment so much that the load shifts to one side and then keeps that side down. A cargo of salt or sugar has some danger attached to it; for if the ship leak, the cargo may be dissolved, and then pumped out with the bilge water, and this will alter the trim. In a fleet coming home from India in 1809, four fine ships were lost in a hurricane off the Isle of France, and from what happened to the other ships which were saved, it is supposed that the saltpetre of the cargoes had been dissolved and pumped out, and that the ships in consequence became unmanageable.

Bladders used by beginners in swimming are dangerous, unless secured so as not to shift towards the lower part of the body.

A great inventor (in his own estimation) published to the world, that he had solved the important problem of walking safely upon the water; and he invited the crowd to witness his first essay. He stepped boldly upon the wave, equipped in a pair of bulky cork boots: but it soon appeared that he had not pondered sufficiently on the subjects of the centre of gravity and of flotation, for in the next instant all that was to be seen of him was a pair of legs sticking out of the water. He was picked up by help at hand, and, his genius cooled and schooled by the event, he was conducted home. Some soldiers once finding a few cork *jackets* among old military stores, determined to try them; but mistaking the shoulder straps for lower fastenings, they put them on as *drawers*, and on then plunging in, with the hope of being able to sit pleasantly on the water, their heavy heads went down, and they were nearly drowned.

When the ice breaks up in the polar regions, on the return of summer, immense islands are set afloat, rising high into the air and sinking deep into the sea. The melting process, in most cases, goes on unequally in the water and in the air, and from the mass changing form, the stability is often lost, and one of the grandest phenomena in nature is produced, *viz.* the overturning of a mountain—the sudden subversion of an island—with a corresponding tumult in the ocean around, often felt at the distance of many leagues.

The phenomena of pressure, floating, &c. in fluids, vary in exact proportion to their weight or specific gravity.

A ship draws less, or swims lighter by one-thirty-fifth in the heavier salt water of the sea than in the fresh water of a river; and for the same reason a man supports himself in swimming more easily in the sea than in a river.

A piece of wood that floats in water will sink in oil.

A man floats on mercury as the lightest cork does on water.

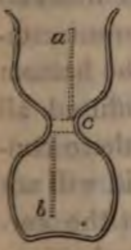
Had the water of our ocean been but a little heavier than it is, men after shipwreck might have died of famine and cold, but would not have been drowned.

Oil floats on water, but sinks in alcohol or ether. The term *proof spirit* means spirit light enough for oil to sink in it, and the strength is proportioned to the lightness.

Cream rises in milk, and forms a covering to it.

Blood, allowed to rest after flowing from the living body, separates into parts, which arrange themselves according to their specific gravities. The buffy coat of inflammation (where this exists) is uppermost, forming the surface of the coagulum which comes next; at the lower part of this there is an accumulation of red globules; and the whole of the solid mass, or crassamentum, floats in the serum, which is therefore lowest of all.

Wine will float on water, if slowly and carefully poured upon it; and in a common sand-glass, if wine be put into the under chamber, and water into the upper one, and a communication be then made between them, the two liquids will change places. And if the lower half of the glass be covered, so as to leave the upper half with the appearance of a simple goblet, the water will seem to have been changed into wine. The liquids are less mixed, and change places sooner, when there is a tube *b* to carry the water down to the very bottom, and a tube *a* to carry the wine up to the top.

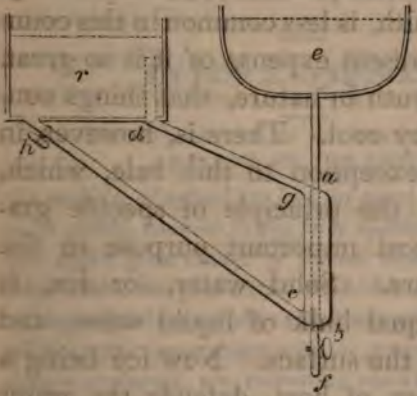


Mercury, water, oil, and air, may be shaken together in the same vessel, and on standing will separate and arrange themselves in the order of their specific gravities.

When, in a mass of water, part of it is heated more than the rest, that part, by its expansion, becomes specifically lighter than the rest, and will rise to the surface. Hence, when heat is applied to the bottom of a vessel to make water in it boil, there is a circulation going on from the first moment until the operation finishes; the hotter part of the water is always rising from the hottest part of the vessel, and the colder part is descending elsewhere.

In the same manner, when a tall glass of hot water is dipped into cold water, a downward current takes place near the sides of the glass all round, and an upward current in the middle. The motion is rendered very remarkable if a few bits of amber be thrown in, for being nearly of the specific gravity of water they rise and descend with the water. On account of the current established in such cases, heat applied to the bottom of a vessel of liquid is soon equally diffused all over it; but heat applied at the top is there confined, because the heated and lighter fluid will not descend. Water may be made to boil at the surface, while a piece of ice lies at the bottom. The converse is impossible.

The current in a fluid, from local change of temperature, is an important part of the following process.—Heat is transferred from one liquid to another, without mixing them, by making the hot liquid descend in a very thin metallic tube through the cold liquid rising around it in a larger tube. Boiling water from the vessel *e*, for instance, may descend slowly by the small tube *e a b f*, which is surrounded from *a* to *b* by cold water ascending through the tube *c g*. Then, as the temperature of two liquids so nearly in contact with each other, will not, after a very short time, differ in any one place more than a few degrees, it follows that the water lately cold, as it rises from the part of the tube *g* where it is so nearly in contact with the boiling water descending, will be nearly boiling, while the water lately hot, on leaving the tube at *b*, where it is in contact with cold water just rising, will be itself nearly cold: and thus equal quantities of hot and cold water will have exchanged temperatures. The flow of the hot water is regulated by a cock *f*, and that of the cold water by the cock *h*. The water rises along *c g d*, because it is hotter and lighter than in *h c*.—The author suggested this principle, with an arrangement of many thin flat tubes for the descending fluid, and a large box to contain these and the rising fluid, as a refrigerator in a distilling apparatus, or for cooling the wort of brewers, or as a



means of diminishing the expense of warm baths. Half the original expense of a great porter brewery is for the construction of the numerous water-tight floors on which the hot wort is thinly spread to cool: and the practice of warm bathing, so conducive to health, is less common in this country, because the present expense of it is so great.

It is a general truth in nature, that things contract in size as they cool. There is, however, in water, a curious exception to this rule, which, operating through the principle of specific gravities, effects a most important purpose in the economy of nature. Solid water, or ice, is lighter than an equal bulk of liquid water, and therefore floats on the surface. Now ice being a very bad conductor of heat, defends the water underneath from the cold air, and preserves it, therefore, in its liquid and useful state, until the return of the mild season. Thus, in ice and snow, nature has prepared a winter garb for the lakes and rivers, as complete and effectual as she has for the tribes of animals, by the periodical thickening of their wool or fur. Had ice become heavier than water, and had it consequently fallen to the bottom, and left the surface without protection, a deep lake might have been frozen in European winters, and have formed a solid mass, which summer suns would no more have melted than they now do the glaciers of Switzerland. But for this important exception, therefore, to a general law of nature, many of the now most fertile and lovely portions of the earth's surface would have remained barren and uninhabited wastes.

CHAPTER III.

DOCTRINE OF FLUIDS.

SECTION II.—PNEUMATICS.

ANALYSIS OF THE SECTION.

If the particles of a fluid are held far apart by a mutual repulsion, which yields, however, to any force applied, so that a mass of the fluid suffers great change of volume under different degrees of compression, the phenomena in which such a fluid is concerned will be modified by its great LIGHTNESS *and* ELASTICITY, *but will still be in strict accordance with the general properties of fluids already explained, viz.* PRESSURE EQUAL IN ALL DIRECTIONS —PRESSURE AS THE DEPTH—LEVEL SURFACE, *and* FLUID SUPPORT. *The pressure of the atmosphere in all directions, and as the depth, is seen remarkably in its effects*—on solids—on liquids:—*and acting in conjunction with heat, it produces the phenomena of* boiling, evaporation, clouds, rain, dew, &c.—*and by varying in degree, it allows certain substances to exist sometimes in the* liquid *and sometimes in the* aeriform *states.*

WHAT a change has taken place in the degree of man's knowledge of nature, since philosophers thought that air was one of four primary elements, *viz.* air, fire, water, and earth, of which all things were composed, and of which each was for ever distinct from the others. We now know that air or gas is merely an accidental state, in which any body may exist, according to the quantity of heat pervading it: the body being solid when the absence of heat allows the atoms to obey freely their natural attraction, and to cohere, as in ice, for instance; being liquid, when so much heat is present as to separate them, and let them slide freely among each other, as they do in water; and being aeriform when still more heat is added, causing the atoms to repel and dart asunder to a great distance, as they do in steam. But in any one of these three states, the various substances are as much themselves as in the others, and at the command of the chemist will assume any of the forms which he desires. As each substance has a different relation to heat, in the variety there are some which at the medium temperature of our earth are solid, some which are liquid, and some aeriform. The solids, in general, are the heaviest under a given volume, and therefore sink down and form the great mass or centre of the earth; liquids follow next in order and float upon this solid centre, filling up its inequalities with a level surface; and the airs are the lightest of all, and as a second ocean rest above the sea and above the highest mountains to an elevation of about fifty miles.—There are two substances, in particular, of which it is the nature to assume the form of air at a very low temperature, *viz.* oxygen and nitrogen, and of these, therefore, the atmosphere chiefly consists, but smaller portions of almost every other substance are found in it. Water, among these supplementary matters, is more abundant than any of the others, and in its various states of cloud, mist, rain, dew, and snow, it serves much to vary the scenes of nature.

The atmospheric ocean is the great laboratory in which most of the actions of life go on, and on the composition of which they depend. A man requires a gallon of fresh air every minute for his breathing, and dies immediately if deprived of it, or if confined to the same. All other animals also require it in various proportions. And in the vegetable creation, the beautiful green leaf or delicate flower is merely a broad and tender expansion of surface for the contact of the vivifying air. Animals give out to the atmosphere a substance which vegetables absorb, and vegetables, by removing this, again fit the air for the use of animals; so that, upon the whole, in the various changes of nature there is a perfect balancing of absorption and exhalation, preserving the great mass in a uniform state, and constantly fit for its admirable purposes.

While the ancients had that notion of the air, which made them apply to it vaguely, and almost indifferently, the names of air, ether, spirit, breath, or life, they never dreamt of making experiments upon it, from a suspicion that it could have any relation to common matter: and it is one of the most beautiful portions of the history of man's progress in knowledge, which exhibits the light gradually breaking in upon this most interesting subject in modern times. Gallileo discovered that air had a definite weight or pressure: Torricelli's and Pascal's ingenuity measured the height of the aerial ocean: Priestly, Black, Lavoisier, and others discovered that air might be united to a metal, so as to increase its weight, and to produce a compound of totally new qualities; and they proved that many of the ores from our mines are merely metals concealed, by being united with one of the ingredients of the atmosphere. They then analyzed the atmosphere itself, and exhibited these ingredients as distinct substances, having each peculiar properties. Within a few years the subject has been thoroughly investigated, and the true nature of air or gas is perfectly understood. We can now take a little of that most light, invisible, impalpable fluid which we breathe, and squeezing the heat out of it by strong pressure, we can make its particles collapse from their aeriform distances, to assume the state of a tranquil oily fluid. This may be retained as such for ever, or may be made solid in combination with other bodies, or may be again set at liberty. And there are certain substances, such as iodine, which instantly pass from the state of solid to that of air, and the contrary.

The suspicion once excited, that air was as much a material fluid as water is, only much less dense, by reason of a greater separation and repulsion of the particles, it was easy to follow out the parallel, and to confirm the supposition by reference to the commonest facts. The motion of a flat board is resisted in water:—the motion of a fan is resisted in the air. Sand, pebbles, and masses of wood, are rolled along or floated by currents of water:—chaff, feathers, and even rooted trees, are swept away by currents of air. There are mills driven by water:—and there are mills driven by the wind. Oil set free under the surface of water, or placed there in a bladder, rises to the surface:—smoke or hot air, and a balloon filled with hydrogen gas, rise in air. A fish swims by its fins in water:—a bird supports itself by its wings in air. But take the water from the vessel in which a fish swims, and it sinks and gasps a few moments, and dies:—so, on exhausting the air from a vessel in which birds or butterflies are enclosed, their useless wings will flap; but if the cruel experiment be continued, they fall to the bottom, and soon die.

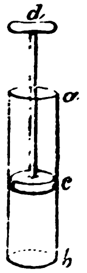
We proceed now to prove that air or gas, as a fluid, differs from the other fluids which we call liquids, only in the circumstance of its extreme lightness or rarity, and in being very extensively elastic; that is to say, in the atoms being so related, that pressure brings them much more nearly into contact, and that on the pressure ceasing, they regain their distance as before.

Lightness of air.

The lightness or rarity of atmospheric air, as it is found on the general surface of the earth, is such, that if a bag of it holding a cubic foot be emptied into the copper ball of an air-gun, by the action of the pump, the ball then weighs about an ounce and a quarter more than before. The same volume of water weighs one thousand ounces. And the other gases, or substances in the aeriform state, have their various specific gravities, just as the same substances have when liquid or solid. Water in the form of air, as it raises the piston of the steam-engine, is only half as heavy as common air; hydrogen is only one-fourteenth as heavy; and carbonic acid gas, which is the air that rises out of soda water, or brisk ale, or champaigne wine, is so much heavier than common air, that it can be poured out of one open vessel into another as a liquid might, or more exactly as water might be poured under oil.

Elasticity of air.

A small bladder full of air may be pressed or squeezed between the hands until it is much reduced in size, and on relieving it from the pressure it will resume its former bulk immediately.



If a tube or barrel of perfectly uniform bore, *a b*, be fitted with a tight plug or piston *c*, covered with leather and oiled, and which will move up and down without allowing the air to pass by its sides, the air between the piston and the close bottom *b* may be compressed to a twentieth or a hundredth of its usual bulk; and, if allowed, it will then push the piston back again with the same force as was used to condense it, and will regain its volume as before the experiment.

Again, if the plug at the commencement of the experiment were only an inch from the bottom, on drawing it up, the inch of air beneath it would expand so as to occupy the whole tube when the piston arrived at the top, having become, of course, proportionally less dense.

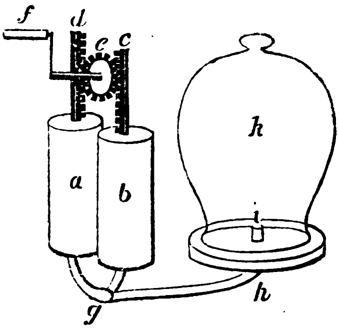
If the question were proposed here, why the air, which admits of such various density, is found to have that certain degree of it which is met with at the surface of the earth? we answer, that as the water, in any place at the bottom of the ocean is pressed with force exactly proportioned to the quantity of water above it, so the air at the surface of the earth bears the pressure of the superincumbent mass of air, and has exactly that density which this is calculated to produce by acting upon its great compressibility. And we shall see below, that the density of the air near the earth is changing with every circumstance which affects the state of the atmosphere above, as winds, clouds, rain, &c., and bears relation to the altitude of the place of observation. The air at the surface of the earth exists in a state of pressure and condensation like the lowermost bags of cotton or wool in a great heap.

The tube and piston described in the opposite page, with certain additions, become to the experimenter either a syringe for condensing air, or a pump for exhausting or removing it from any vessel; and both operations depend on the elasticity of air.

A barrel and piston is a *condensing syringe*, when, in the passage of communication between the bottom of the syringe and the receiving vessel, there is a flap or valve which allows air to pass towards the receiver but not to return. The piston, therefore, at each stroke forces the fill of the barrel of air into the receiver. When the piston is lifted again after the stroke, air re-enters the barrel from the atmosphere, either through a valve in the piston, or through a small hole made near the top of the barrel.

That useful contrivance, *a valve*, for whatever purpose used, and in whatever way formed, is in principle merely a moveable flap placed on any opening, and held against it by its gravity, or by some other very gentle force. Such a flap, it is evident, will allow fluid to pass only one way through the opening, *viz.* outwards from it; for fluid tending to pass inwards, presses the flap the closer, the greater its entering force.

To convert the forcing syringe or pump into an exhausting syringe or pump, commonly called an *air-pump*, it is only necessary to change the direction of the valves; then, when the piston is pressed down, all the air between it and the bottom, instead of entering the vessel as in the last case, escapes by the valve in the piston itself, towards the atmosphere, and on afterwards raising the piston a perfect vacuum would be left under it, but for the valve below, which is then opened by the elasticity of the air in the receiver, and allows a part of this air to follow the piston. Thus, at each stroke, a portion of the air is removed from the receiver, proportioned to the size of the pump-tube. In a good air-pump there are always two similar pumping barrels, *a* and *b*, to quicken



the operation of exhausting, and the pistons are worked by the same winch or handle *f*, turning the pinion *e*, which acts on the teeth of the piston rods *d* and *c*. Both pumps open into a tube *g h*, of which the end is seen at *h* rising tightly through the round plate of the machine at *i*. This plate is so flat and smooth, that a glass bell *k*, with a smooth ground lip, when placed upon it, forms an air-tight joining. On working the pump, such a bell is exhausted of its air, and fitted for showing the many interesting phenomena which the air-pump can display, and which will pass under review as we proceed. The supporting frame-work of the pump is not shewn here.

The law of the elasticity of air is, that its spring or resistance to compression, is proportioned always to its density. Hence in any case, by finding either the density or the spring or the compressing force, we know all the three.

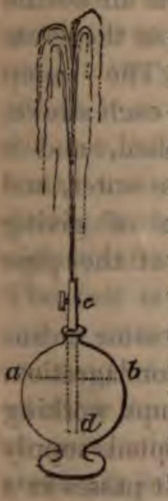
It is found by experiments described a few pages further on, that the atmosphere above the surface of the earth weighs, and therefore presses, fifteen pounds on every square inch of it, and that the air near the earth, and of course under this pressure, has the density indicated by an ounce troy to the cubic foot. And we further find that such air is reduced to half its bulk, or becomes of double atmospheric density, by an additional pressure of fifteen pounds on the inch, and of triple density by triple pressure, and so on; and on the other hand, that it dilates to double bulk if the pressure be diminished to half, and to any greater bulk, even beyond a thousand-fold, if the pressure be diminished in a corresponding degree. And air bearing a certain force of pressure, is a spring acting with that force on whatever surrounds it.

It is very important to be familiar with this law, for it holds with respect to all aeriform fluids as well as common air; and it therefore throws light on the action of steam-engines, air-guns, and all pneumatic machines. It also explains the condition of our atmosphere as to its density at various elevations; telling us, for instance, that when a balloon has risen through half of the atmospheric mass, the air around it will only be of half the density which exists at the surface of the earth.

We know not exactly to what extent the rarefaction of air may go by removing pressure; in other words, at what distance the gravity of the particles becomes just a balance to their mutual repulsion, and therefore we know not what the degree of rarity is at the top of our atmosphere: but we see that it must be exceeding great, from the fact of the air left in the receiver of an air-pump having still spring enough to lift the valve under the working piston, when less than a thousandth of the original quantity remains. In the most perfect air-pumps the machine itself is made to raise the valve, that the exhaustion may be as complete as possible.

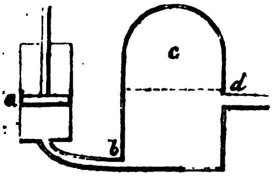
The expansion of air is illustrated by placing a bladder, with a very little air in it, under the receiver of an air-pump. On then exhausting the receiver, the bladder is seen to swell as the operation proceeds, and at last appears quite full. In swelling, it will lift a weight laid upon it, and may even burst. The explanation of this phenomenon is, that at first the air in the bladder is condensed air, like all air at the surface of the earth under the pressure of the superincumbent atmosphere; and its volume increases as that pressure is diminished by the air-pump. It is rarefied exactly in the same proportion as the air which remains in the receiver surrounding it.

In the ball of an air-gun—which is a strong globular vessel of copper attached under the lock, the air is condensed thirty or forty times as much as in the atmosphere around it, therefore the pressure is thirty or forty times fifteen pounds on the inch; and when the valve is opened for an instant by the action of the lock, the air issues and propels the charge with this force. The effect of air thus condensed nearly equals that of gunpowder, and one charge of the ball suffices for many shots.



If a bottle or vessel *a b*, partly filled with water, be corked, and have a tube passed through the cork to near the bottom of the water, and if air be then forced in through this tube so as to become more condensed in the upper part of the vessel: on turning the cock *c*, which opens the tube, the elasticity of the condensed air will press the water out as a beautiful jet rising from the pipe to a height proportioned to the density of the air. Or if such a vessel, with air of common density, be placed under a tall air-pump receiver, on working the pump, the jet of water immediately rises.

The elasticity of air is rendered very serviceable near great water-pumps, such as those used for the supply of cities. A pump can only throw its water by a distinct gush at each stroke, while the current through the pipe towards the city should be quite uniform. This object is attained by causing the gushes from the pump *a* to enter by *b* at one side of a large vessel *c*, of which the upper half is full of air, and from the other side of which, at *d*, the water issues on its journey. The air in this vessel (called the air-vessel) is soon so condensed by the entering water, that its resisting elasticity forces the water along the pipe *d*, and each entering gush has only the effect of compressing the air a little more for the moment, while the flow in the great pipe continues nearly uniform. The pump itself is made to take in a little air at each stroke, so that the vessel is always supplied, and a little is constantly passing on with the water, and effecting the highly useful purpose of giving an elasticity to the whole contents of the pipe and its ramifications.



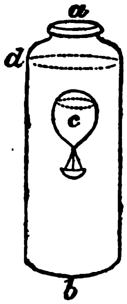
The same object is attained by the same means in the fire-engine used to check conflagration. This has in general several water-pumps working together, which throw their interrupted supply into an air vessel, and from thence it passes in a uniform jet to the point desired.

The compressibility and corresponding spring of air are remarkably exhibited in that singular contrivance of modern times, the *diving bell*. It is a vessel in which men can descend with safety to great depths in the ocean, there to reside and labour, so as to attain many objects of high importance to them. The recovery of sunken treasures by it is a trifling matter—but it enables them to pursue works of submarine architecture, and to construct light-houses and noble harbours, where formerly no foundations could have been laid. The diving bell, in point of utility, has proved a remarkable contrast to its sister invention—the balloon; which last, although so wondrously bearing man aloft to the regions of the clouds, takes him there for little advantage, and with danger, nay, often with destruction to life.

The diving bell is a large heavy open-mouthed vessel, with accommodation in it for one or more persons. It is let down into the water from a ship or barge fitted to it, with its open mouth undermost. On first entering the water it appears full of air: but air being compressible according to the law now explained, and the pressure of the water around the bell increasing exactly as it descends, the volume of the air gradually diminishes, and at thirty-four feet it is reduced to half. The bell is then, of course, half full of water, and a person breathing in it receives twice as much air into the lungs at each inspiration as when at the surface. A constant supply of fresh air is sent down to the bell by a forcing pump above; and the heated and contaminated air, which has served for respiration, and which rises to the top of the bell, is allowed to escape by a cock placed there for the purpose. The men who have to work at some distance from the bell have tubes of communication with it, by which they inhale the air required; and they allow this, when used, to rise through the water above them. A man cannot breathe comfortably by such a tube if he be either much above or below the level of the water in the bell: for if above, the air in the bell is more compressed than his chest, and is forced towards him so as to require an effort to control its admission; and if below, his chest is bearing greater pressure than the air in the bell, and he must therefore act strongly with the muscles of the ribs to draw the air down to him. A phenomenon similar to this takes place when two bladders of air are connected by a long tube, and are immersed in water to unequal depths; the air is always strongly forced from the lower into the upper one, because the lower one is more forcibly pressed. The difficulty of pumping air down to the diving bell increases, of course, with the depth to which it has descended: for if the bell be so low that the water is pressing on the air in it with a force of fifteen pounds per inch (which would happen at thirty-four feet), it is evident that a syringe or pump cannot inject more air unless it act with a force greater than this. Men now work in the diving bell and about it with so little discomfort, that the wages of submarine labour are very little higher than of any other.

It is remarkable, now that the use of the diving bell has become so familiar, that a kindred and still more simple means has not been introduced for certain purposes, particularly of sudden emergency, such as to aid in the recovery of the bodies of drowning persons. A ten-gallon cask, or vessel of any kind, filled with air and made heavy enough to sink in water, with a breathing tube from it like those of diving bells, would be a provision of air for a man under water for ten minutes, and with this under his arm, he might instantly descend from a boat, or walk from the shore into water of any depth, to recover the body of a fellow-creature lately sunk, and in time probably to save the life, which a few minutes wasted in waiting or in unsuccessful dragging would suffer to be lost. The tube would issue from the upper part of the vessel, and there would be an opening at the bottom to allow water to enter to compress the air proportionally to the depth, and to replace it as used. The author would propose this as an addition to the apparatus of the Humane Society for the recovery of persons apparently drowned.—It shews how remote from common trains of thinking the truths are connected with the constitution of our atmosphere, when a means so simple and easily procured as that now described, should never have been thought of or tried in any way by pearl-fishers, or by those who gain their bread by diving to recover things dropped overboard in harbours or anchoring stations, and who have hitherto been limited to the single gulp of air which they take on descending. In any case of a man working under water, cask after cask of air might be sent down to enable him to remain as long as necessary.

There is an exceedingly beautiful philosophical toy, of which the action depends chiefly on the elasticity of air; and as it moreover illustrates most of the laws of fluidity, it is deemed worthy of description here. It is a small balloon or thin globe of glass *c*, with an opening at the bottom, and having its little car or basket hanging to it. If put to float in water while the globe contains air only, it is so light that half of it remains above the surface; but water may be introduced into the globe so to adjust the specific gravity, that it may be only a little less than that of water. If such a balloon be placed in a tall jar of water *a b*, the mouth of which is closely covered by bladder-skin or India rubber tied upon it, on pressing such covering with the hand, the balloon will immediately descend in the water: it will rise again when the pressure ceases, and will float about, rising, or falling, or standing still, according to the pressure made. The reason of this is, that pressure on the top immediately condenses the air between the water surface and the cover; this condensation presses upon the water below, and by influencing it through its whole extent, compresses also the air in the balloon globe, and forces just as much more water into this as to render the balloon heavier than water, and therefore heavy enough to sink. As soon as the pressure ceases, the elasticity of the air in the balloon repels again

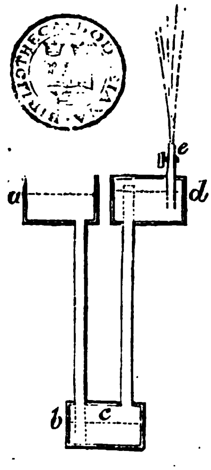


the lately entered water, and the machine being then lighter than water, ascends to the top. If the balloon be adjusted to have a specific gravity to nearly that of water, it will not rise of itself after once reaching the bottom, because the pressure of the wate rthen above it will perpetuate the condensation of the air which caused it to descend. It may even then, however, be made to rise again by inclining the water jar to one side, so that the perpendicular height of water over it shall be diminished.

This toy proves many things—the *materiality* of air, by the pressure of the hand on the top being communicated to the water below through the air in the upper part of the jar—the *compressibility* of air by what happens in the globe just before it descends—the *elastic force* of air when, on the pressure ceasing, the water is again expelled from the globe—the *lightness* of air in the buoyancy of the globe—it shews that in a fluid *the pressure is in all directions,* because the effects happen in whatever position the jar be held—it shews that *pressure is as the depth,* because less pressure of the hand is required the farther that the globe has descended in the water—and it exemplifies many circumstances of *fluid support.* A young person, therefore, familiar with this toy, has learned the leading truths of hydrostatics and pneumatics, and has had much amusement as well as instruction.

On the same principle as the balloon now described, three or four little figures of men may be formed of glass, hollow within, and each having a minute opening at the heel. If these be placed in a jar like the balloon, and be adjusted by the quantity of water admitted into them, so that they shall all differ a little in specific gravity, on pressure being made on the cover of the jar, the heaviest will descend first, and the others in succession; and they will stop or return to the surface in reverse order when the pressure ceases. A person exhibiting these figures to people ignorant of the subject seems to have the power of ordering their movements as he wills. If the jar containing the figures be inverted, and the cover be placed over a hole in the table, through which pressure can be made upon it unobserved, by something rising through the hole and obeying the foot of the exhibitor, the most amusing and surprising evolutions may be produced among the little men, in perfect apparent obedience to word of command.

The beautiful fountain, called the fountain of Hero, by which water is made to spout far above its source, depends for its action upon the elasticity of compressed air. The vessel *d* is first filled with water, while *b* and *a* contain air only. On then pouring water into *a*, the water of *d* immediately darts upwards through the jet pipe *e*, to an elevation nearly equal to the length of the tube from *a* to *b*. The reason is, that the water from *a* descends by the tube to *b*, and com-



presses the air at *c*, which compression, conveyed along the tube from *c* to *d*, acts on the water in the vessel *d*, and causes it to jet. The pressure being produced by the column of water *a b*, the jet is proportioned to the length of that column.

Having now explained the two peculiarities which distinguish aeriform from other fluids, *viz.* their *lightness* and extensive *elasticity*, we proceed to shew that they have the four other properties already described under hydrostatics, as belonging to fluids generally : and first

" *Pressure in all directions.*" (*Read the analysis at pages* 226 *and* 285.)

A quantity of air or gas shut up in any vessel, and compressed, is equally affected throughout, and its tendency to escape is equal in all directions, as is proved by the force necessary to keep similar valves close wherever placed. Hence the hydrostatic press and hydrostatic bellows, described in last section, which depend for their action on this law, may be worked by air or gas as well as by a liquid.

Owing to this law, air, if allowed, will always rush from where there is more to where there is less pressure. The actions of the common fire bellows, and of the animal chest in breathing, blowing, sucking, &c. are so many instances.

The suddenness with which any compression made on part of a confined aeriform fluid is communicated throughout the whole, is seen strikingly in the simultaneous increase or burst of all the gas lights over an extensive building, or even a town, at any instant when the force supplying the gas is augmented.

Many very interesting illustrations of the fluid pressure of air acting in all directions will occur under the next head, mixed up with proofs of the atmospheric pressure being as the depth.

"*Pressure as the depth.*" (*Read the analysis.*)

On first approaching this subject, one may be surprised to find the depth of the atmosphere mentioned as something perfectly ascertained, although no man can ever have approached the surface to measure it; but science often furnishes means of discovering precise truth, where ignorance does not even dream of the possibility.—It may facilitate the apprehension of this point as regards air, to describe first a similar case as regards water.

The bottom of a lake supports all the water in the lake, and each portion bears just the weight of the water directly over it: a means then of ascertaining the weight or pressure on any portion of the bottom will tell how much water there is over it, and as we know the bulk of a given weight of water, will tell how deep it is at that part. In like manner, the ocean of air which surrounds the globe rests with its whole weight upon the surface of the globe, and each portion of the surface bears its own share: by ascertaining then the pressure of the atmosphere on a given extent of surface, we find how much air is standing directly over it; in other words, the weight of a column of air resting on such surface as its base, and reaching to the top of the atmosphere. Now having the weight of the whole column, and the weight of a cubic foot of air at the bottom of it (ascertained as described at page 289) and knowing the law of aerial elasticity, we determine the height of the column by a simple calculation. Most accurate experiments shew that the weight of air over every square inch of the earth's surface is nearly fifteen pounds, producing the same pressure that would be made by an additional ocean of water of thirty-four feet in depth, or by an ocean of quicksilver of thirty inches; and from this fact, and the ascertained lightness and elasticity of air, we find that its depth on earth must be nearly fifty miles. The remaining part of this section has chiefly to trace and to prove the effects of such a mass of matter resting upon the earth's surface, and embracing every thing placed there.

Water is a substance much more obvious to the human senses than air, and is constantly under observation; yet many of its most important agencies escape the notice of common observers. Few persons, for instance, discover of themselves the law explained in last section, of the pressure increasing in it as the depth: but when they find that a piece of cork plunged deep into water is compressed to a fourth of its bulk, and that strong empty vessels of glass, and even of metal, are crushed inwards by the weight, and that pieces of sunken wood are filled with water through all their internal structure, so as to become heavier than stone, &c., the mind is roused, and at last perceives every where the influence of the law. If the truths of hydrostatics thus escape notice, we need not wonder that those of pneumatics are still longer in forcing themselves on our attention.

If a common drinking glass or tumbler be filled with water, and a piece of bladder be tied closely over its mouth, on allowing it to sink to the bottom of a mass of water, and to stand there with its mouth upwards, the bladder skin exhibits no signs of being pressed upon, although bearing on its upper side the whole weight of the water immediately above it: the reason is that the water beneath the bladder resists just as strongly as that above presses: but if, by means of a syringe or pump, the water be extracted from within the glass, the bladder itself will then have to bear the whole pressure of the water above it, and will probably be torn or burst. The degree of pressure, and consequently the depth of water, in such a case, might easily be ascertained, by placing some support of which the action could be measured under the bladder, to sustain it after the removal of the interior water.—Now this phenomenon may be exactly copied in our atmosphere or sea of air. A glass held in the hand is immersed in the fluid air, and is full of it, as the other glass was of water: its mouth may be covered over with bladder, and no external pressure will be apparent, because there is a resistance of the air within, just equal to the pressure of the air on the outside. But if the air be extracted from under the covering, by means of an air pump acting through an opening in the bottom of the glass, the bladder is first seen sinking down and becoming hollow from the weight of the air over it, and at last bursting inwards with a great noise or crack. By placing a circular piece of wood under the bladder skin, in such a case, for it to rest on, and a spring of known force to support the wood, we may ascertain very nearly the weight and pressure of the air over it. The problem, however, can be solved more elegantly and accurately by means of the barometer to be described further on. This phenomenon of the atmospheric pressure is often shewn by placing the hand on the mouth of a glass so as to cover it closely, and by then extracting the air from underneath the hand: the weight of the atmosphere holds the hand down upon the mouth of the glass with a force of fifteen pounds on the inch.

As should follow, from the pressure of fifteen pounds per inch thus detected at the surface of the earth being the weight of our superincumbent atmosphere, we find that exactly as we rise from the earth, the pressure diminishes. This fact now furnishes the readiest means of acertaining the height of mountains and of balloon ascents, as will be explained in considering the barometer.

After the many explanations now given of fluid pressure being equal in all directions, it is almost superfluous to remark, that the downward weight of the atmosphere of fifteen pounds on the inch becomes a pressure in all directions, and that the bladder described above would be as readily burst if turned sideways as if turned directly upwards; therefore every body on the surface of the earth, dead or living, solid or fluid, is compressed all around with this force.

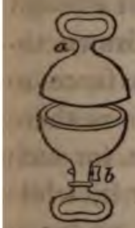
“ *Atmospheric pressure on solids.*”

The atmosphere, then, presses on the two sides of a plate of glass or metal, with force of fifteen pounds on the inch, although no sensible effect follows, because the opposite pressures counterbalance; but if two plates of smooth glass or metal be laid against each other, and if air be prevented from entering between them at their edges, they cannot be separated by less force than fifteen pounds per inch of their surface.

To draw the piston of a syringe from the bottom of its barrel, while no air is allowed to enter between them, requires force of fifteen pounds to the square inch of surface of the piston. But if the experiment be made in the exhausted receiver of an air-pump, the piston falls by its own weight, and is pushed back immediately on readmitting the air. And whenever there is a vacuum produced at the surface of the earth, there is an external pressure, to the extent stated, seeking admittance all round.

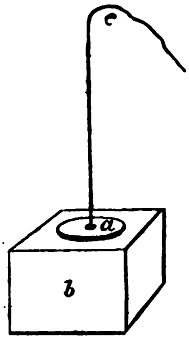
The receiver of an air pump of five inches diameter has nearly twenty square inches of surface in its upper part or roof, and bears a weight of atmosphere of twenty times fifteen, or three hundred pounds. While it has air within it, this pressure is exactly balanced and is not sensible: but when exhausted on the plate of the air-pump, it is pressed to the plate with this force. As the atmospheric pressure is in all directions, the pump plate of course is equally pressed upwards against the receiver, and the sides of the receiver are pressed towards each other. This explains why the air-pump receivers must be made arched or of dome-shape to withstand the great pressure. A flat piece of glass of great thickness, laid upon the upper mouth of a receiver, so as to form an air-tight cover to it, is broken instantly by exhausting the air beneath it; and a bottle or receiver with flat sides suffers in the same manner.

Illustrative of this pressure on solids is the experiment of the Magdeburgh hemispheres, as it is called. Two hollow half globes of metal, *a* and *b*, are fitted to each other, so that their lips when touching may be air-tight. While there is air between them or within, resisting the pressure of the outward air, these hemispheres can be separated from each other without difficulty; but when the air is exhausted from within by the air-pump, a force of as many times fifteen pounds is required to separate them as there are square inches in the area of the mouth. The air is extracted by unscrewing one of the handles at *b*, and then connecting the remaining stalk (which is hollow, and has a stop-cock) with the air-pump.



This experiment merits recollection, because it was one of the first which drew attention to the subject of the material nature and properties of the air; and it astonished the world. Otto de

Guericke, of Magdeburgh, the inventor, had hemispheres made of a foot diameter, and six coach-horses of the emperor were unable to pull the halves asunder. There being no air-pump at that time, Guericke emptied the balls of their air by first filling them with water, and then pumping this out by a pump or syringe at the bottom.



It is a phenomenon of the same kind, when a boy with his foot presses a circular piece of wet leather *a*, against a large stone *b*, and then tries to detach it by pulling at a cord *c*, rising from its centre. If the leather be so close in its texture that air cannot pass through it, and stiff enough not to be puckered or drawn together, he must exert a force to detach it of as many times fifteen pounds as there are square inches of surface covered by it, for such is the weight or pressure of the air over it, while there is no counterbalancing pressure under it nearer than on the other side of the stone. If this *sucker*, as it has been called, be attached to a loose stone which weighs less than the weight now mentioned, the stone may be lifted by it. A very large *sucker* applied upon a rock or wall, would resist the pull of horses just as the Magdeburgh hemispheres do.

The simple contrivance now described seems excellently adapted to a purpose of obstetric surgery, *viz.* as a substitute for the steel forceps in the hands of men of little manual dexterity, whether this depends on inexperience or on natural inaptitude. The consideration of it in this light properly belongs to the next medical section: but as its true mode of action is not very readily conceived by persons who either have never been instructed in the general laws of physics, or who have ceased to be familiar with them, it is thought preferable to make the few following remarks here. A *pneumatic tractor* (for so the author would propose to designate the contrivance) of three inches in diameter, would act upon any body, to lift or draw it, with a force of about a hundred pounds, and with much more, therefore, than is ever required or allowable in obstetric practice. As in lifting a stone, the tractor does not act as if it were glued or nailed to a part of it, but bears or takes off the atmospheric pressure from one part, and allows that on the opposite side, from not being then counterbalanced, to push the stone in the direction of the tractor; so when applied upon the head, it would not at all pull by the skin in the manner of a very strong adhesive plaster applied there, as uninformed persons would be apt to suppose, but by taking off a certain atmospheric pressure from the part of the head on which it rested, it would allow the pressure on the other side or behind to urge the head forward on its way. Of course the acting pressure in such a case is not made on the head directly, but through the intervening parieties and contents of the abdomen. It would be preferable always to have a gentle and diffused action of the tractor over a large space, rather than an intense action on a small space, and therefore a tractor for the purpose now contemplated should not be very small, and should have a little air underneath it in a slight depression or cavity at its centre.—The tractor may be used to assist in raising depressed portions of a fractured skull, and might thus sometimes save the operation of trepanning. It would be preferable to a small cupping glass for such a purpose, because it is perfectly inactive, except during the instants when pulled at; while a cupping glass keeps up a continued flow of blood to the part, and might thereby do injury. The tractor, however, might be made to answer the common purposes of cupping glasses, where these could not be obtained, both to prepare a part for scarification, and afterwards to increase the flow of blood from the punctures.

It is from having feet that act on the principle of the tractor, that certain insects can walk along ceilings with their bodies hanging downwards; and there are fishes which attach themselves to rocks, or other objects, by a similar action.

If two pneumatic tractors be applied to each other, men pulling opposite ways, to separate them, must act with a force of fifteen pounds to the square inch of the surface of contact. This experiment approaches in its nature to that of the Magdeburgh hemispheres.

The action of this tractor may be well exemplified under water. A body with a flat surface, applied to a flat bottom, so as perfectly to exclude the water, bears the whole weight of the water over it, and requires great force to detach it. And in like manner, under mercury, a flat piece of cork pushed against the smooth bottom of the vessel, so as to expel the mercury from between them, is held down by the weight of the column of mercury above it, and by the weight of the atmosphere over the mercury: which weight adds a pressure of fifteen pounds to every inch on the surface of a body thus immersed in any liquid.

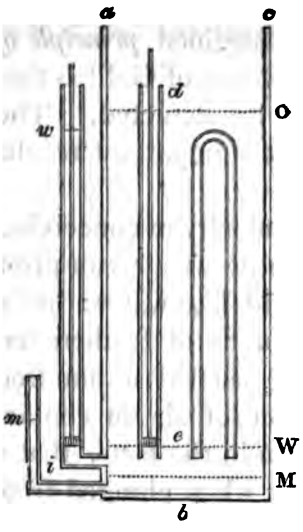
" *Atmospheric pressure on liquids.*"

The pressure of the atmosphere on liquids produces many striking effects, and now that we comprehend them, we wonder that they should have been so long misunderstood. It is familiarly exemplified in the action of pumps and syphons. All such phenomena, in former times, were referred to what was called *nature's horror of a vacuum*, or to an obscurely imagined *principle of suction*. It was not until the time of Galileo that their true nature began to be detected. The discovery has led to many very important results in the arts.

Persons may at first have difficulty in conceiving how a fluid so rare and subtile as air can press upon or affect a dense liquid like water: but a man carrying a hundred pounds of feathers has just as great a load as if he carried a hundred pounds of lead. The action of air in contact with water is familiarly shewn in the facts, that a vessel does not fill with water when plunged from the air into it with the mouth downwards, and that when a tube open at both ends has been partially immersed in water, and therefore partially filled, the water can be forced out of it by blowing air with the mouth in at the upper end.

That there is fifteen pounds' weight of air above every square inch of the earth's surface, has already been proved, in our consideration of the atmospheric effects upon solids; and we now proceed to shew that the many remarkable phenomena among liquids, which long appeared so mysterious, are merely the necessary consequences of the same pressure upon them. It will facilitate the comprehension of these effects, if we first view them as they may be produced by more visible agents, *viz.* by one liquid pressing upon another—oil, for instance, upon water.

It has already been said, that an ocean of oil spread over the earth, to have the same weight as our atmosphere, would require to be about thirty-seven feet deep. A deep vessel, then, *a b c*, with water in it up to the level W, and with thirty-seven feet of oil above this, up to the level *o*, is fitted to exhibit many of these phenomena. We may first remark that the weight of the oil would not at all disturb the le-



vel surface of the water at W, although pressing on it with a force of fifteen pounds to the inch.

One effect of this pressure would be, that in proportion as the oil entered the vessel, the water would rise in such a tube as *i w* issuing from its bottom, as already explained by the figure at page 259 (which see); and when there were fifteen pounds of oil on the inch, the water in *i w* would stand thirty-four feet high.—If these thirty-four feet of water were then lifted out of the tube by a piston drawn up from the bottom of it at *i*, a second equal quantity would be pressed up by the oil, as before, and the tube and piston would constitute a pump. Now if the atmosphere instead of the oil is allowed to press upon the water surface in such a vessel, but is excluded from the tubes, the water still rises thirty-four feet, as in the last case; and if this quantity be lifted out of the tube by a piston, a second equal quantity will be pressed up, and the tube and piston will exemplify our common pump.

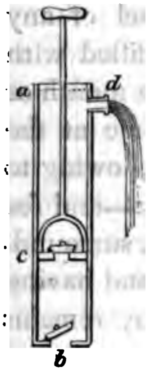
Again, if there were a quantity of quicksilver at the bottom of the vessel up to the level M, and if a tube *i m* issued from under this level, the quicksilver would rise in it as the water did in the last experiment; but, by reason of its greater specific gravity, it would only reach thirty inches while the water stood at thirty-four feet. Now thirty inches of mercury is the height of column which the atmospheric pressure acting in the same way produces, as is seen in the similar apparatus made expressly for shewing this, and called a *barometer*, (or *measure of weight*)—an instrument which, as it indicates distinctly certain changes which take place in the weight of the atmosphere near it, has become of great importance, as will appear a little farther on.

Again, if a tube *d*, of an inch square, and open at both ends, were plunged into the oil, it would of course always be full up to the level of the oil on the outside of it; and if it were pushed low enough to enter the water at W, it would just have fifteen pounds of oil in it. The inch of water surface at its mouth, therefore, would be bearing a weight of fifteen pounds, like the surface around, but would not yield, owing to the force with which it tended upwards to escape from the pressure corresponding to its depth in the oil; and if, by a piston or plug at *e* in the tube *d*, the fifteen pounds of oil were lifted out of it, water would rise into it until enough had entered to reproduce the pressure of fifteen pounds on the surface below as before: that is to say, the water would rise thirty-four feet, as in the external tube *w i*; this tube and piston, also, would form a pump.—In like manner, in a tube open at both ends, and plunged from the air into water, the air presses on the surface of the water within the tube, as well as around it, with a force of fifteen pounds to the inch, and the water surfaces are not affected by the equal pressures; but if we lift the air out of the tube by a piston, as we did the oil in the last experiment, the water will then rise thirty-four feet, following the piston. This arrangement of parts is the most usual in what is called the lifting or household pump.

Again, if a common bottle or a vessel of any other shape, as the bent tube *e*, were filled with water, and plunged under the oil until its mouth or mouths reached below the water surface at the level W, it would remain full of water, owing to the pressure of the oil surrounding it:—and for the same reason, any such vessel or tube, surrounded only by the air, if filled with water, and having its mouth or mouths plunged into water, remains full; and if one end of the tube be longer than the other, a current is established, and the contrivance is called a *syphon*.

A fish in the water below the level W would be bearing the pressure of the oil from O to W, as well as that of the water; so a fish in any water open to the air, bears the atmospheric pressure of *fifteen pounds per inch*, in addition to that of the water itself. This is proved by extracting the air from over water in which a fish is swimming: for then the air-bag of the fish, situated near its under side, as already described, immediately dilates and turns the fish upon its back.

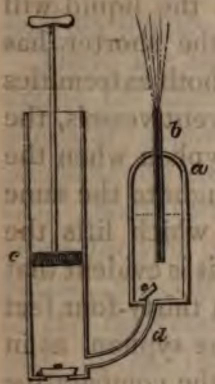
To separate the Magdeburgh hemispheres, or to produce a vacuum in any way, under the water level W, would require force proportioned to the weight of oil above, (here and in all the preceding cases we suppose the oil to be protected from the pressure of the atmosphere); and to separate the Magdeburgh hemispheres under any water surface pressed upon by the atmosphere, requires *fifteen pounds per inch* more than what balances the effect of the water itself.



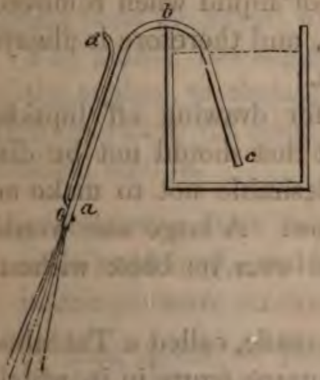
The common *lifting pump*, then (or *sucking pump* as it used to be called), is merely a barrel *a b*, with a close-fitting plug or piston in it *c*. When the lower end *b* is plunged into water, and the piston is raised from the bottom, the atmosphere being prevented from pressing on the surface of water within the tube, its pressure on the surface external to it drives the water up after the piston. That the water which thus rises may not fall again, there is a valve or flap at the lower part of the pump barrel *b*, which only allows the water to pass upwards; and that the piston may be allowed to pass downwards through the water in the pump barrel, to repeat its stroke, there is a similar valve in it. The piston, in rising during the second stroke, causes all the water above it to run over at the spout *d*.

Formerly a lifting pump was said to act by sucking the water up from the well beneath it; but we now see that the piston merely lifts something which was pressing on the water in the barrel, and allows the water to rise, in obedience to the external pressure around. And the reason is now apparent why, in the lifting pump, the water will only follow the piston to a certain elevation.

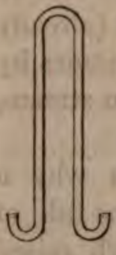
The animal action of sucking is an approximation to what we have been describing in the lifting pump. The difference is, that the chest or mouth can only make a partial vacuum, and therefore cannot raise a liquid very far.



When the piston of a pump is solid, or without a valve, as at *c*, the machine is called a *forcing pump*. The water enters beneath the piston, as already explained, and then, as it cannot rise through the piston, it is forced by its descent into another direction, as to *d*. A lifting-pump can only bring water from thirty-four feet below the piston, but a forcing-pump can send it to any elevation. In forcing-pumps, it is usual to make the water enter an air vessel *d a* (already explained at page 296), from which it issues by the elasticity of the air in a nearly uniform stream, through the pipe *b*.



The reason why a syphon remains full of liquid, although raised above the general surface of the liquid, was given in page 316. For common purposes, a syphon is made of the form here represented, *viz.* a bent tube *a b c*, with one end longer than the other. To use it, the end *c* being immersed in liquid, and the end *a* being stopped with the finger, the air is extracted by the mouth, or in any other way, through the small tube *d a*, and immediately the atmosphere fills it with liquid from *c*: if then left to act, the liquid will run from the longer leg, until the shorter has drunk up all within its reach. If both extremities be immersed in liquid, and in different vessels, the liquid will only be at rest in the syphon when the surfaces in the two vessels are brought to the same level. As it is the same cause which lifts the water in a pump and in a syphon, it is evident that the top of a syphon must be within thirty-four feet of the water surface below. In the syphon, as in all hydrostatic cases of this kind, the comparative diameters of the legs is of no importance, nor their oblique length; the perpendicular heights alone of the two columns indicate the necessary relation. A syphon is sometimes made with both legs equal and turned up, as here represented, so that it remains full of liquid when removed from the vessel, and therefore is always ready for action.



The syphon is used for drawing off liquids, where there is a sediment that should not be disturbed, or where it is desirable not to make an opening in the vessel below. A large one would empty a lake or mill-pond over its bank without injuring the bank.

A pretty syphon toy is made, called a Tantalus' cup. It has a standing human figure in it, which conceals a syphon, rising by one leg to reach the level of the chin, and then descending by the other leg to pierce through the bottom of the cup towards the reservoir below. On pouring water into the cup, the syphon begins to act as soon as the water reaches the chin, and the cup is emptied as if by magic.

There are some of the infinitely varied water-drains or courses in the bowels of the earth, which are syphons, and which hence produce the phenomenon called an intermitting well or fountain. Some of these alternately run for a day, and cease for two or three, or for a longer or shorter period, according to the comparative magnitudes of the reservoir and the drain, The reservoir may be an internal cave of the mountain, receiving a regular supply of water by a slow filtering of moisture from above, and its drain must be a syphon-formed channel, which, when in action, carries off the water faster than it is supplied. There are some fountains that flow constantly, but at regular intervals have a remarkable increase. In such cases, a common spring must be joined with a syphon-spring.

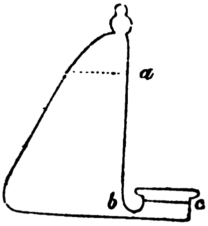
The author has suggested a useful application of the syphon, to obviate a strong objection to the high operation for stone, as explained in the next medical section.

The following facts have close relation to those now explained, and further illustrate atmospheric pressure on liquids.

A long glass of jelly, if inverted with its mouth just under warm water, will be found soon to have lost the jelly, but to be full of water instead. The jelly melted by the heat is heavier than water, and sinks down, while it is replaced by water from below, sent up by the atmospheric pressure.

The slaves in the West-Indies steal rum occasionally, by inserting the long small neck of a bottle full of water through a hole in the top of the rum cask. The water falls out of the bottle into the cask, and the lighter rum ascends to its place.

In the common fountain lamp, the provision of oil is in a vessel which has its mouth downwards, but the mouth being immersed in a little oil below it, the surface of which is nearly on a level with the flame, no oil can escape from above but as the flame consumes this free oil, and then more descends to replace it.



The common water glass for bird cages has only one opening, near the bottom at *b*, and yet the water only escapes by this when the level of the water at *c* in the open part, is low enough for a little air to pass into the body of the glass by the channel *b*. An ink glass made on this principle preserves the ink well, because there is so small a surface exposed to the air; and the glass may be of large size so as not to require frequent replenishing.

It is the direct weight or downward pressure of the atmosphere on liquid surfaces which we have hitherto been contemplating; but in the following instances we have proof of the same pressure acting upon them in all directions.

If a bottle or cask be filled with water, and closely corked, and if a small hole be then drilled in the bottom or side, the water will not escape by it, owing to the resisting pressure of the atmosphere, and to there not being room in the opening for a current of air to enter while the current of water escapes; but if a hole be drilled in the top as well as in the bottom, a jet from the lower opening will follow immediately, because then the air presses on the upper surface of the liquid as well as on the lower, and the weight of the liquid is free to act.

Thus also a cask of beer or wine cannot be emptied by a cock near the bottom, unless what is called a vent-hole may be made at the top. If the dependent opening, however, in any case be very large, the air will enter on one side of it while the liquid escapes at the other, as is seen in decanting a bottle of wine. It is the pressure of the air that makes a difference between the manner in which liquid issues from an inverted bottle and from an open funnel.

But even a large opening at the bottom of a vessel which is close every where else, may be prevented by the pressure of the air from discharging liquid, if the mutual passing of the two currents of air and liquid be rendered difficult. A wine glass filled with water, and covered by a loose bit of paper laid upon its mouth, may be inverted, and if the paper be held in its place during the turning, the pressure of the atmosphere against the paper will then keep it in its place, and will support the water above it. Any tube of water, if shorter than thirty-four feet, may be kept closed at the bottom in the same way.

The animal body is made up of solids and fluids, and the atmospheric pressure affects it accordingly. It appears paradoxical at first, that a man's body should be bearing a pressure of fifteen pounds on every square inch of its surface, and yet that he should remain altogether insensible to such an influence; but it is the fact, and reflection discovers that his not feeling it is owing to the circumstance of the fluid pressure being uniform all around: it discovers also that if a pressure of the same kind be even many times greater, such, for instance, as fishes bear in deep water, or as a man supports in the diving bell, it must equally pass unnoticed. Fishes are at their ease in a depth of water where the pressure around instantly breaks or bursts inwards almost the strongest empty vessel that can be sent down; and men walk on earth without discovering a heavy atmosphere about them, which however instantly crushes together the sides of a thick steam engine boiler, which has been accidentally left for a moment without the counteracting internal support of steam or air.

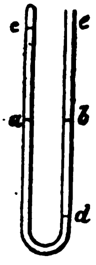
The fluid pressure on animal bodies, thus unperceived under ordinary circumstances, may be rendered instantly sensible by a little artificial arrangement. In water, an open tube partially immersed becomes full to the level of the water around it, and the weight of the water contained in it is supported by that immediately below its mouth. Now a flat fish resting closely against the mouth of the tube would evidently be bearing on its back the whole of this weight—perhaps one hundred pounds; but the fish would not thereby be pushed away, nor would it even feel its burden, because the upward pressure of the fluid immediately under it would just counterbalance. But if, while the fish continued in the supposed situation, the one hundred pounds of water were lifted from off its back by a piston in the tube, the opposite upward pressure of one hundred pounds would at once crush the body of the fish into the tube and destroy it. At a less depth, or with a smaller tube, the effect might not be fatal, but there would be a bulging or swelling of the substance of the fish into the mouth of the tube. In air and in the human body a perfectly analogous case may be exhibited: a man without pain or peculiar sensation, lays his hand closely on the mouth of a vessel containing air, but the instant that the air within the vessel is withdrawn by the pump, the now unresisted pressure of that on the outside fixes the hand upon the vessel's mouth, causes the flesh to swell or bulge into it, and makes the blood ooze from any crack or puncture in the skin.

These last few lines almost describe the surgical operation of *cupping*, the essential circumstances of which are the application of a cup or glass having a smooth blunt lip, to the skin of the part, and the extraction of a portion of the air contained in the cup by a syringe or other means, so that the flesh may swell underneath. It may facilitate to some minds the exact comprehension of this phenomenon, to consider what happens when a small bladder or bag of India-rubber full of any fluid, is pressed between the hands on every part of it's surface except one—at that one part the bag swells, and even bursts if the pressure be strong enough. So in cupping, the whole body except the surface under the cup is squeezed with a force of fifteen pounds to the square inch, while in that one situation the pressure is diminished according to the degree of exhaustion in the cup, and the blood consequently accumulates there. This part of the operation is called the dry cupping: to complete it, the cup is removed and the tumid part is cut into by the simultaneous stroke of a number of lancet points, and the cup being again used as before, the blood rushes forth under the diminished pressure. The partial vacuum in the cup may be produced by a syringe, or by previously burning a little spirit in the cup, so that the momentary dilatation produced by the heat in the instant before the cup is applied, may drive out the greater part of the air. The human mouth applied upon a part becomes a small cupping machine, and in former times was used as such to poisoned wounds. One wonders that the present perfect cupping glasses, of stronger and more permanent operation, are not always used, as they might be, to remove the poison after the bites of rabid or venomous animals.

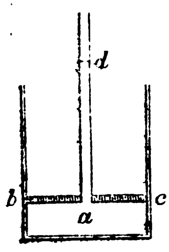
The author has suggested an extension and modification of the operation of dry cupping, which he believes will prove a very important remedy in the hands of the medical practitioner; it is intended as a substitute for bleeding in cases where blood can ill be spared, and as a more sudden and effectual check to inflammatory disease, in certain cases, than even bleeding itself. It is explained in the next medical section of this work.

There is an effect of the atmospheric pressure on the living body which is rarely thought of, although of much importance, *viz.* its keeping all the parts about the joints firmly together by an action similar to that on the Magdeburgh hemispheres. The broad surfaces of bone forming the knee joint for instance, even if not held together by ligaments, could not be separated by a force of less than about a hundred pounds while the capsule surrounding the joint remained air-tight. In the loose joint of the shoulder this support is of greater consequence. When the shoulder or other joint is dislocated, there is no empty space left, as might be supposed, but the soft parts from around are pressed in to fill up the natural place of the bone. When a thigh bone is dislocated, the deep socket called the acetabulum instantly becomes like a cupping glass, and is filled partly with fluid and partly with the soft solids. In all joints it is the atmospheric pressure which keeps the bones in such steady contact, that they work smoothly and without noise.

The barometer, we have seen at page 316, is a column of fluid supported in a tube by the pressure of the atmosphere, and therefore indicating most exactly the degree of that pressure. It is an instrument now of such importance, both in a scientific point of view and in the business of common life, that for the sake of minds which conceive such subjects with difficulty we add here the following further illustrations of its nature.



If mercury be poured into a bent tube open at both ends, it will stand at the same level in the two legs, as at *a* and *b*, and the air will be pressing on the two surfaces at *a* and *b* with equal force. If the air be then removed from one leg *a*, by a piston or otherwise, while it continues to press in the other leg *b*, the mercury will be pushed down in *b*, until the growing height of the column in *a* be as much greater than of that in *b* as just to counteract the pressure: now this takes place, in fact, when the mercury in *a* stands about thirty inches higher than in *b*. If the top of the tube *a* were then closed permanently, the mercury would for ever remain in it, marking most perfectly the atmospheric pressure. Now this construction, the empty and useless part of the tube above *d* being cut off, forms a common barometer. The exact altitude of the mercury in it is known by observing how much the surface near *c* is higher than that near *d*. Occasionally, in this kind of barometer, a little float is placed on the mercurial surface at *d*, and by a thread passing from it, is made to move an index like the hand of a clock, which tells the changes of elevation. This modification is called the *wheel barometer*.



Again, if a quantity of water *a* in the bottom of a closed pump barrel were pressed upon by the piston *b c*, of which the rod *d* were hollow or tubular, the water would rise in the rod in exact proportion to the pressure made by the piston. Now a barometer tube is as this hollow piston rod, into which the mercury or water rises, while the atmospheric pressure around is as the piston forcing it up. To make a barometer of this kind it is only necessary to procure a glass tube, close at one end and about three feet long, and then having filled it with mercury, to plunge its mouth (stopped by the finger while turning) into a small cup or basin of mercury. The fluid then falls away a little from the top of the tube, leaving a perfect vacuum there, and stands at that elevation which the atmospheric pressure is fitted to maintain. We know, from the law of hydrostatics already explained, that it is of no importance in such a case what the shape, or inclination, or size of the tube may be, as only the perpendicular height can measure or be measured by the pressure.

Galileo had found that water would rise under the piston of a pump only to a height of about thirty-four feet; and his pupil Torricelli conceived the happy thought, that the weight of the atmosphere might be the cause of the ascent, and that mercury therefore, which is about thirteen times heavier than water, might only rise under the same influence to a thirteenth of the elevation. Experiment proved that this was so, and the mercurial barometer was invented. To afford further evidence, this was afterwards carried to the tops of buildings and of mountains, and it fell always in exact proportion to the part of the atmosphere left below it;—and water pumps were found to vary in their power according to the same law.

It was soon discovered, by careful observation of the mercurial barometer, that it did not always stand at the same elevation; in other words, that the weight of atmosphere over any particular part of the earth is constantly fluctuating: a truth which, without the barometer, could never have been suspected. This discovery led to important results. It was remarked, that in serene dry weather the barometer generally stood high, and that it fell before and during storms and rain: it might therefore serve as a prophet of the weather, and become the precious monitor of the husbandman or the sailor.

The reasons why the barometer falls before wind and rain will be better understood a few pages hence; but we may remark here, that when water which has been suspended in the atmosphere, and has formed a part of it, separates and begins to fall as rain, the weight of the mass is diminished; and that wind generally occurs when a sudden condensation of aeriform matter, in some particular situation, disturbs the equilibrium of the air, and causes that around to rush towards the situation of diminished pressure.

To the husbandman the barometer is of considerable use, by aiding and correcting his prognostication of the weather drawn from local signs familiar to him; but its great use as a weather-glass seems to be to the mariner, who roams over the whole ocean, under skies and climates altogether new to him. The watchful captain of the present day, trusting to this extraordinary monitor, is often enabled to take in sail and to make ready for the storm, where, in former times, the dreadful visitation would have fallen upon him unprepared.—The marine barometer has not yet been in general use for many years, and the author was one of a numerous crew who probably owed their preservation to its almost miraculous warning. It was in a southern latitude. The sun had just set with placid appearance, after a beautiful afternoon, and the usual mirth of the evening watch was proceeding, when the captain's order came to prepare with all haste for a storm. The barometer had begun to fall with appalling rapidity. As yet, the old sailors had not perceived even a threatening in the sky, and they were surprised at the extent and hurry of the preparations: but the required measures were not completed, when a more awful hurricane burst upon them than the most experienced had ever braved. Nothing could withstand it; the sails, already furled and closely bound to the yards, were riven away in tatters; even the bare yards and masts were in great part disabled; and at one time the whole rigging had nearly fallen by the board. Such, for a few hours, was the mingled roar of the hurricane above, of the waves around, and of the incessant peals of thunder, that no human voice could be heard, and, amidst the general consternation, even the trumpet sounded in vain. In that awful night, but for the little tube of mercury which had given the warning, neither the extraordinary strength of the noble ship, nor the skill and energies of the commander, would have saved one man to tell the tale. On the following morning the wind was again at rest, but the ship lay upon the yet heaving waves, an unsightly wreck.

The marine barometer differs from the common one, in having the tube contracted in one place to a very narrow bore, so as to prevent the sudden rising and falling of the mercury, which every motion of the ship would else occasion.

Civilized Europe is now familiar with the barometer and its uses, and therefore, to renew in Europeans the first feelings connected with it, they may observe the astonishment or incredulity with which people of other parts still regard it. A Chinese once conversing on the subject with the author, could only imagine of the barometer that it was a gift of miraculous nature, which the God of Christians gave them in pity, to direct them in the long and perilous voyages which they undertook to unknown seas.

The state of the atmosphere, as to weight, differs so much at different times in the same situation as to produce a range of about three inches in the height of the barometer; that is to say, from twenty-eight to thirty-one inches. On the occasion of the great Lisbon earthquake, the mercury fell so far in the barometers, even in Britain, as not to be visible in that portion at the top usually left uncovered for observation. This part is commonly of five or six inches in length, with a divided scale attached to it, on which the figures 28, 29, &c. indicate the number of inches from the surface of the mercury at the bottom to the respective divisions. On the lower part of the scale the words *wind* and *rain* are generally written, meaning that when the mercury sinks to them, wind and rain are to be expected; and on the upper part of the scale *dry* and *fine* appear, for a corresponding reason: but we have to recollect that it is not the absolute height of the mercury which indicates the existing or coming weather, but the recent change in its height. A falling barometer tells of wind and rain; a rising one of serene and dry weather.

The barometer answers another important purpose, besides that of a *weather-glass*—in enabling us to ascertain readily the height of mountains, or of any situation to which it can be carried.

As the mercurial column in the barometer is always an exact indication of the weight of a column of the air above it of equal base with itself, and reaching from the place of the barometer to the top of the atmosphere—as explained in the foregoing paragraphs—the mercury must fall when the instrument is carried from any lower to any higher situation, for it escapes from the pressure of that portion of the atmosphere then left below its level; and the degree of falling must always tell exactly how much air has been left below. If thirty inches barometrical height mark the whole atmospheric pressure at the surface of the ocean, and if the instrument be found to stand at only twenty inches when carried to some other situation, it proves that one-third of the atmosphere exists below the level of the new situation. Now if the atmospheric ocean were of as uniform density all the way up as our watery oceans, a certain weight of air thus left behind in ascending would mark every where the same change of level, and the ascertaining any height by the barometer would become one of the most simple calculations. As the air at the surface of the earth is about twelve thousand times lighter than its bulk of mercury, an inch rise or fall of the barometer would mark every where a rise or fall in the atmosphere of twelve thousand inches, or one thousand feet. But owing to the elastic nature of air, which causes its volume to increase as it escapes from pressure, the atmosphere is rarer in proportion as we ascend, and the rule of one inch of mercury for one thousand feet ascent holds only for rough estimates near the surface of the earth. The precise calculation, however, for any case, is still very easy; and a good barometer, with a thermometer attached, and with tables or an algebraical formula, founded on observation of all the influencing circumstances, enables us to ascertain elevations much more easily, and in many cases more correctly, than by trigonometrical survey.

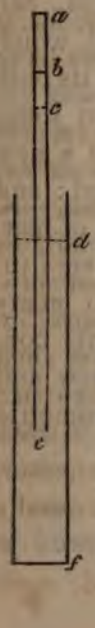
The weight of the whole atmospheric ocean surrounding the earth has been ascertained to be equal to that of an additional watery ocean of thirty-four feet deep, or of a covering of mercury of thirty inches; and as the air at the surface of the earth is eight hundred and forty times lighter or more bulky than water, if the same density existed all the way up, the atmosphere would be *thirty-four* times *eight hundred and forty*, or about *twenty-eight thousand* feet high, which is equal to five miles and a half: but on account of the elasticity of air, and the consequently greater rarity of the superior regions of the atmosphere, it really extends to a height of nearly fifty miles. It is easy to prove, *à priori*, from the laws of aerial elasticity, what is found to hold in fact, that one-half of all the air constituting our atmosphere exists within three miles and a half from the earth's surface; that is to say, under the level of the summit of Mont Blanc. A person unaccustomed to calculation might suppose the air more equally distributed through the fifty miles than this fact indicates, as the same person might suppose a tube of two feet diameter to hold only twice as much as a tube of one foot, although in reality it holds four times as much.

In carrying a barometer from the level of the Thames to the top of St. Paul's Church in London, or of Hampstead Hill, the mercury falls about half an inch, marking an ascent of about five-hundred feet. On Mont Blanc it falls to half of the entire barometric height, marking an elevation of fifteen thousand feet; and in Du Luc's famous balloon ascent it fell to below twelve inches, indicating an elevation of twenty-one thousand feet, the greatest to which man has ever ascended from the surface of his earthly habitation.

The extreme rarity of the air on high mountains must of course affect animals. A person breathing on the summit of Mont Blanc, although opening his chest as much as usual, really takes in at each inspiration only half as much air as he does below—a contrast to the man in the diving bell, who, at thirty-four feet under water is breathing air of double density; at sixty-eight feet of triple; and so on. It is known that travellers, and even their practised guides, often fall down suddenly as if struck by lightning when approaching lofty summits, on account chiefly of the thinness of the air which they are breathing; and some minutes elapse before they recover. It appears, therefore, that although our atmosphere be fifty miles high, it is so thin beyond three miles and a half, that mountain ridges of greater elevation than this are nearly as effectual barriers between nations of men as are islands or rocky ridges in the sea, between the finny tribes on the opposite sides of them. The intense cold which appertains to high situations, and which forms another obstacle to human approach, remains to be considered in our next division.

A barometer connected with an air-pump, will indicate exactly the progress and degree of exhaustion in the receivers. When the mercury falls to half it's height, it shews that half of the air is extracted; and so in all other proportions. Hence a barometer is a necessary appendage to a complete air-pump; but as its chief purpose is to shew when the exhaustion is carried to the required degree, a very short one, corresponding to the bottom of a common barometer, is all that is generally provided, and it is usually made of syphon form.

Professor Leslie's ingenious new method, mentioned at page 266, of ascertaining the specific gravity of the solid material forming any porous mass or powder, includes the agency of a barometer. It proceeds upon this reasoning. The interstices of a porous or pulverized mass are filled with air of the density of the surrounding atmosphere, and if the atmospheric pressure on which that density depends be diminished upon the mass in a known degree, an exactly corresponding proportion of the air will issue from the pores, which, if we can measure it, will declare the whole quantity, and therefore the quantity of interstice in the solid mass. Now if the substance were enclosed at the end of a tube or syringe, the pressure of the atmosphere might be taken off from it by a piston, and the air would issue from the pores as described, and would follow the piston. Mr. Leslie conceived the happy idea of substituting for this solid piston, of which it would be difficult to measure the precise action, the liquid piston of a mercurial column, of which the force is always proportioned to the length. He takes an open glass tube, *a e*, of known dimensions, and prepares a part of its top, *a b*, as a receptacle for the substance under trial, by affixing a partition at *b*, which shall support the substance, but allow passage to air. Having then filled *a b* with the substance, he immerses the tube in mercury contained in the wider tube or vessel *d f*, until the mercury stand both inside and outside at the



level of *b*. It is evident that, on then closing the top of *a* in an air-tight manner, and lifting the tube *a*, a column of mercury will be lifted in it above the level of the external mercury at *d*, and will be acting as a piston pulling down from *b* with force proportioned to the height of the column. Now if the tube be lifted until the mercurial column *c d* be just half the length of the column in a common barometer, the air in the pores of the substance will be relieved from half the atmospheric pressure, and will dilate to double bulk, and while half will remain in the pores, the other half will issue forth and will occupy the space *b c*, between the surface of the mercury and the partition at *b*. This space *b c*, therefore, will be exactly equal to the amount of the interstices; and as it may be measured and compared with the whole space *a b*, its ascertained magnitude will solve the problem. Mr. Leslie has found in this way that charcoal, which is usually said to be only half as heavy as its bulk of water, is formed of matter really seven times heavier than this supposition; proving, in a new way, the identity of charcoal and diamond: and he has found light pumice-stone to consist of matter heavier than granite or marble. His very ingenious thought may lead ultimately to many useful results, and the contrivance merits consideration here, as exhibiting under a new and interesting aspect the rationale of the barometric action and the elasticity of air.

Atmospheric pressure determining the liquid or aeriform state of certain substances. (See the analysis, page 285.)

It has already been stated that the gases, or substances in the aeriform state, may be reduced to their liquid, or even solid form, by simple pressure, and by allowing at the same time the heat, which was combined with them in the aeriform state, to escape. Common air, nitrogen, carbonic acid, the common coal gas, &c. have been treated in this way. Now it becomes an important question whether many of those substances which we at present see as liquids on the face of the earth, where they are bearing the pressure of the atmosphere, might not appear as airs if that pressure did not exist, or were removed.

On investigating this subject by experiment we accordingly find, that ether, alcohol or ardent spirit, volatile oils, &c., and even water itself, are only known to us here as liquids, because their particles are kept together by the weight and pressure of a superincumbent atmosphere. Any of these substances, relieved by art from such pressure, immediately becomes an air or gas, just as a common gas, kept in the state of liquid by the pressure of a great depth of water, or any other, would become air again on being relieved.

In our first chapter we explained the dependance of the three forms which any body may assume, of solid, liquid, or air, on the quantity of heat diffused among the particles. We now see however that, to understand the matter completely, we must also consider the effect of accidental pressure: for, while heat is the power separating the atoms in the changes mentioned, it has to overcome both the mutual attraction of the atoms and the force of the atmosphere pressing them together. We shall understand the combined influence of these forces, when we have examined carefully the two phenomena called *boiling* and *evaporation*, which exhibit the progress of the change of a liquid into an aeriform fluid.

If water be placed in a suitable vessel over a common fire, or over the flame of a lamp, it is gradually heated to a certain degree, and then small bubbles of aeriform matter (which in water is called steam) are seen forming at the bottom of the vessel, and successively rising to the surface, where they disappear by mixing with the atmosphere; and the operation being continued, the quantity of water diminishes with every bubble, and soon all vanishes under the new form of air.

This change takes place in water, under common circumstances, at the exact degree of heat marked 212° in Fahrenheit's thermometer:—in other substances it takes place at other fixed temperatures.—The relation of water to heat, therefore, is such, that at 212° of that thermometer, the repulsive power is just sufficient to overcome both the natural attraction of its particles, and the compressing force of the atmosphere of fifteen pounds on the inch. A less degree of heat is sufficient to make water boil, if the pressure of the atmosphere be lessened or removed; and a greater is required if pressure be increased. This is seen in the following facts.

Water boils on the top of Mont Blanc at 180°, because relieved from the pressure of the air below the level of that mountain's summit; and at all intermediate heights in descending to the level of the sea, or in mines below that level, where, of course, the atmospheric pressure is greater than above, there is a corresponding increase of the boiling temperature. So exactly is this the case, that it is now found to be a good method of ascertaining the heights of places, merely to observe the heat of boiling water at them.—The water near the bottom of a boiler, for a like reason, is the hottest, for the pressure being proportioned to the depth, water would remain tranquil at the bottom which would give out steam a little higher up. In very large and deep boilers, therefore, such as are used in great porter breweries, the liquor is much more heated than it can be in smaller vessels; and this circumstance may have an influence on its ultimate quality.

While water under common atmospheric pressure, or when the barometer stands at thirty inches, boils at 212°, other substances, with other relations to heat, have their *boiling points* higher or lower: ether, for instance, boils at 98°; spirit or alcohol at 174°; fish-oil and tallow at about 600°; mercury at 650°.

It is in consequence of the different temperatures at which the particles of different substances acquire repulsion enough to rise against the atmospheric resistance, that the chemist is enabled to perform the operation of distilling. If a mixture of spirits and water, for instance, be heated up to 180°, the spirit will pass off in the aeriform state, leaving the water behind, and may then be caught and condensed in a fit receiver. Distillation is the best means we possess of separating many substances from each other: as spirit from wine—various acids from water—water itself from its impurities—mercury from gold, which it has served to dissolve from among the rubbish of the mine or of the river bottom.

We must recall to mind here what was mentioned in a former part of the work, that a large quantity of heat combines with every substance during its change of form from solid to liquid, or from liquid to air; which quantity, from not remaining sensible to the thermometer, has received the name of *latent* or *concealed heat*. The same is given out again in the contrary change. In the conversion of water into steam, the heat which thus disappears is about 1000°, or six times as much as is required to raise the cold water to the boiling point; this is proved by the time and fuel expended, and by the fact that a pint of water in the form of steam will combine instantly with six pints of cold water, and will raise the whole to boiling heat.

If a little heat be abstracted from steam, a part of the steam proportioned to the abstraction will be immediately condensed into water. What is called steam in common language—as the vapour issuing from a tea-urn or boiling kettle—is not truly *steam*, but small globules of water mixed with air. Steam is as dry and invisible as pure air; but the instant that it comes in contact with air colder than 212° it becomes water, and the exceedingly small particles being then uniformly scattered, it exhibits the appearance so familiar to us.

But for the fact of latent heat, the conversion of a liquid into air would not be the gradual process of boiling which we see, but a sudden and terrible explosion: for when any quantity of water had been raised to the boiling heat, one degree more would be sufficient to convert the whole into steam: and but for the same reason, the thawing of winter snow would be a sudden and frightful inundation. On the other hand, if water had not to give out its latent heat in freezing, after a quantity of it were once cooled down to the freezing point, the abstraction of one degree of heat more would convert the whole into a solid mass. Thus, then, effecting most important purposes in nature and art, all changes from solid to liquid and from liquid to air, and the converse changes from air to liquid and from liquid to solid, are very gradual.

This fact of *latent heat*, obvious as it appears when now stated, has been known but of late. The discovery of it led to those improvements of the steam engine, which have since had such an effect upon the destinies of the British empire. Dr. Black of Edinburgh, and James Watt of Glasgow, are the two names honoured by connexion with it and its consequences.

By means of the exhausting air-pump on one side, and of the condensing syringe on the other, all the above facts, depending on the atmospheric pressure, and its increase or diminution, may be strikingly shewn. Thus water not heated by several degrees to the boiling point of ordinary low situations, but which would be boiling at the top of Mont Blanc, is made to boil immediately under the receiver of an air-pump by a few strokes of the piston, which reduce the density of the contained air; and if the exhaustion be rendered complete, the water will boil even when less warm than the blood of animals by 20°: and at any temperature, however low, water in a vacuum assumes rapidly the form of air, in that case, however, without exhibiting the violent agitation of boiling. Other liquids, as spirits, ether, &c. requiring less quantities of heat to separate their atoms to aeriform distances, boil under the receiver of an air-pump at very low temperatures. Ether boils when as cold as freezing water.

On the other hand, if we confine the atoms of liquids still more than by a common atmospheric or equivalent pressure, degrees of heat above the common boiling point will be required to separate them. In a diving bell at sixty-eight feet under the surface, the boiling point of water is 272° instead of 212°, and at all other depths it is higher than 212° just in proportion to the depth. At the surface of the earth, if we heat water in a close vessel into which we have forced air to press thirty pounds on the inch instead of fifteen pounds, as the atmosphere does, or from which we prevent the steam from escaping until it has acquired the force of a double atmosphere, we shall have to raise the heat in a corresponding proportion beyond 212° before the liquid boils. Under a very strong pressure, water may be rendered almost red hot, but the force with which the atoms are then tending to separate is that of inflamed gunpowder. Even then if only a gradual issue were allowed, a certain quantity of the water would absorb and render latent the excess of heat above 212° and would become common steam, leaving a considerable portion as boiling water of the ordinary temperature.

The fact that liquids are driven off, or made to boil by less degrees of heat when the atmospheric pressure is lessened or removed, has been recently applied to some very useful purposes.

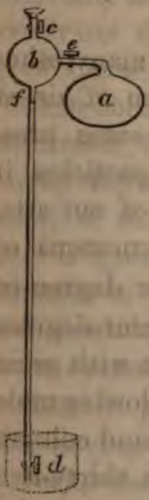
The process for refining sugar is to dissolve impure sugar in water, and after clarifying it, to boil off or evaporate the water again, that the dry crystallized mass may remain. Formerly, this evaporation was performed under the atmospheric pressure, and a heat of 218° or 220° was required to make the syrup boil, and by this degree of heat a portion of the sugar was discoloured and spoiled, and the whole product was deteriorated. The thought occurred to Mr. Howard, that the water might be dissipated as effectually by boiling the syrup *in vacuo*, and therefore at a low temperature. This was done accordingly; and the saving of sugar and the improvement of quality have been such as to make a share of the patent, which secured the emoluments of the process to certain parties, worth many thousand pounds a year. The syrup, in this process, is not more heated than it would be in a vessel simply exposed to a summer sun.

In the preparation of many medicinal substances, also, the process of boiling *in vacuo* is equally important. Many watery extracts from vegetables have their virtues impaired or lost by a heat of 212°; but when the water is driven off *in vacuo* the temperature need never be higher than blood heat, and all the activity of the fresh plant remains in the extract.

In the same manner in the process of distilling, which is merely the receiving and condensing again in appropriate vessels the aeriform matter raised by heat from any mass, substances which are changed and injured by an elevated temperature, may be obtained of admirable quality by distillation in a vacuum. The essential oils of lavender, peppermint, &c. never had the natural flavour and virtues of the plants until this plan was adopted within the last few years.

The influence on the human system, of vegetable medicines thus obtained, is so different from that of the old preparations, that the practitioner requires to advert to it carefully in writing his prescriptions.

The apparatus for evaporating and distilling *in vacuo* consists of vessels strong enough, when quite empty, to bear the atmospheric pressure, and therefore generally arched outwards; and the vacuum is made and maintained by air-pumps driven by a steam-engine or otherwise, or by expelling the air by the direct admission of steam, and then condensing the steam.



The author proposes a very simple contrivance to answer the purpose of such air-pumps and steam-engines or apparatus, and which in many instances therefore might be preferable. It is merely to establish a communication between a close boiler, as *a*, and the vacuum at the top of a water barometer, as *b*. The strong vessel *b* forming the top of the barometer, and thirty-six feet of tube below, reaching to *d*, are first filled with water through a cock *c* at the top; this cock being then shut, and the cock *d* at the bottom being opened, the water will sink down out of the vessel *b* until the column in the tube be only thirty-four feet high, as at *f*, that being the height which the atmosphere will support. On then opening a communication between the boiler *a* and the vacuum in *b* the operation goes on as desired, and the steam rising from *a* may be constantly condensed in *b* by a little stream of cold water allowed to run through it from above. This water, it is evident, would always pass downwards to the column below, without filling up or impairing the vacuum. If air should find admittance in any way, the perfect vacuum can easily be reproduced as at first. The author planned this arrangement as a simple apparatus for the preparation of medicinal extracts; and it appears particularly well-suited for the manufacturing of sugar in the colonies, where air-pumps and nicer machinery can with difficulty be either obtained or managed. On many sugar estates there is a fall of water, which would supply the barometer without the trouble of pumping. The tube *d c* need not be perpendicular, provided it be longer in proportion to its obliquity, and it may be very small; some yards of common lead pipe would answer.

Understanding now that water and many other liquids would be existing in the form of air at common temperatures were it not for some pressure opposing the separation of the particles, it becomes of great importance in many of our arts, and for comprehending certain phenomena of nature, to ascertain very exactly the degree of expansive force which belongs to different degrees of temperature. This has been done with great care, as to water particularly, and the following table shews part of the results. The left-hand column marks temperatures of the water from thirty-two degrees of Fahrenheit's thermometer, or the freezing point, to 290°; and the right-hand column marks the corresponding degrees of force in the vapour, from one ounce and a half per square inch, which is the force of steam rising from freezing water, to sixty pounds per inch, which is the force of stream rising from water heated to 290°.

At 32° force of steam is	1½ oz. per inch.
50	2¾ oz.
100	13 oz.
150	4 lbs.
180	7½ lbs.
212	15 lbs.
250	30 lbs.
272	45 lbs.
290	60 lbs.

In this table we have to remark how much more rapidly the force of the steam increases than the degress of temperature; for a rise of eighteen degrees, *viz.* from 32° to 50°, at the beginning of the scale, only increases the force one ounce and a quarter on the inch, while an equal rise at the top of the scale, *viz.* from 272° to 290°, increases it fifteen pounds. This circumstance, imperfectly understood, has led to many vain schemes for improving the *steam engine.* The truth is, that the density of steam is greater always exactly as its force is greater, and the heat absorbed in its formation is proportioned to the density: hence the force and the cost in caloric or fuel have always the same relation to each other, at whatever density the steam is put to use. In one pint of steam at 290°, having an elastic force of sixty pounds on the inch, there is just four times as much water and four times as much latent heat as in one pint of steam at 212°, which has a force of fifteen pounds on the inch. It does not accord with the plan of this work to enter into the minute detail of this subject, but they may be found in Dr. Ure's excellent Dictionary of Chemistry, under the title CALORIC.

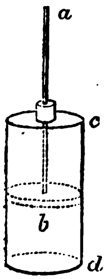
Seeing the rapid increase of the expansive force in the above table, we have the explanation of the terrible effects occasionally produced by confined water overheated. A boiler of any kind, if completetely closed and having no safety valve, will explode as if charged with gunpowder. Unhappily the instances are too numerous where the incautious or ignorant use of steam has produced explosions, which have scattered buildings and destroyed whole neighbourhoods.

To this part of our subject belongs the consideration of that mighty engine, which cannot now be mentioned without a feeling of admiration and gratitude, *viz.*

The Steam Engine,

which since it sprung to its present state of perfection, through the genius of WATT, has, in a few years, changed the direction of human industry, and elevated man in the scale of existence. It may be said to have already much altered and improved the face of the world, and still we are every day witnessing new applications of its utility.

The name of *steam engine,* to most persons, brings the idea of a machine of the most complicated nature, and hence intelligible only to those who devote much time to the study of it; but this is an error, for he who can understand a common pump may understand a steam engine: it is in fact only a pump in which the fluid becomes the *power* instead of the *resistance.* It may be described simply as a strong barrel or cylinder *c d,* with a closely fitting piston *b* in it; which piston is driven up and down by steam admitted alternately above and below it from a suitable boiler; and the end of the piston rod *a,* at which the whole force may be said to be concentrated, is connected in any convenient way with the work that is to

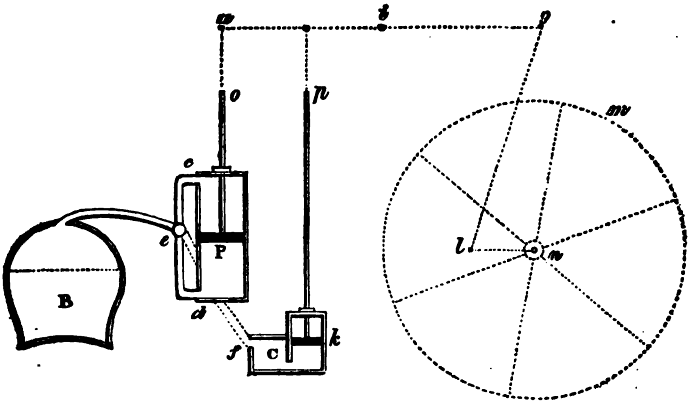


be performed. The power of the engine is of course proportioned to the size or area of the piston, on which the steam acts with a force of fifteen, twenty, fifty, or one hundred pounds to each square inch, according to its density. In some of the Cornish mines there are cylinders and pistons of more than ninety inches in diameter, on which the pressure of the steam equals the effort of six hundred horses.

Sometimes the piston-rod of a steam engine is made to act upon one end of a great beam, while to the other end, immense water-pumps are connected, whose motion causes almost a river to gush up from the bowels of the earth. At other times acting on a crank, it is made to turn complicated machinery; and one steam engine, stretching long arms over a great barrack or manufactory, keeps thousands of spinning-wheels in constant motion in one quarter, while it is carding the material in another, and weaving the cloth in a third. In like manner, one steam engine in a great metropolitan brewery is seen at the same time grinding the malt in one place, and pulling up supplies of all kinds from waggons in the street in another, it is pumping cold water into some of the coppers, and sending the boiling wort from others up to lofty cooling-pans, over which it is turning the fans; it may also be working the mash-tub, drawing water from the deep wells under-ground, loading the drays—in a word, performing the offices of a hundred hands. In some manufactories this resistless power is seen with its mechanic claws seizing masses of the tough iron, and in a few minutes delivering them out again pressed into thin sheets, or cut into bars and ribands, or moulded to any form, as if the iron had become as soft clay in the hands of the potter. One steam engine four miles from London is at the same instant filling all the house reservoirs and baths and fountains of the finest quarter of the town. Now for some years this wonderful piston-rod, working at its crank, has been turning the paddle-wheels of innumerable steam boats in all parts of the world; and, by setting at defiance the violence of the winds and waves, and the currents of the fleetest rivers, it is carrying men and civilization into the most remote recesses of all the great continents. To wherever a river leads, the region, although concealed perhaps since the beginning of the world, is now called from its solitude to form a part of the great garden which civilized man is beautifying. —Such, and many more, are the prodigies which the steam engine is performing!

In the following enumeration of the parts of the steam engine, a minute description is not at all intended, but merely such as will explain the philosophy or general nature of the machine, and as should serve to render interesting a visit to any place, where a steam engine is in operation.

The part which first claims attention is the great *barrel*, *c d*, with its *piston* P, which is moved up and down by the action of steam entering alternately above and below it. The barrel or cylinder is bored with mathematical accuracy, and



the piston is padded round the edge with hemp or other soft material, so as to make it perfectly air or steam-tight. Lately pistons have been made altogether of metal, and in some cases these answer even better than the others, because they have less friction. The next part to be examined is the *boiler* B, which is made of suitable size and strength. The steam passes from it along the pipe B *e*, and by a cock or valves (which may be variously made and placed) at *e*, it is directed alternately to the upper and under part of the barrel; and while it is entering to press on one side of the piston, it is allowed to escape from the other, either to the atmosphere for high pressure engines, or into the condenser at C for those of low pressure. *The supply of steam* from the boiler to the cylinder is regulated by a valve placed somewhere in the pipe B *e*, and made obedient to what is called the *governor*,—a contrivance already described at page 66, to illustrate centrifugal force. It consists of two hanging balls made to revolve by attachment to some turning part of the machinery, which, when they turn at all faster than the assigned rate, shewing that the engine is going too fast, fly apart and affect the steam valve so as to narrow the passage; and on the contrary, when they turn slower than at their proper rate, they collapse, and by so doing open the valve wider. The *supply of water* to the boiler is regulated by a float on the surface of the water contained in it, which, when it descends too low by reason of the consumption of water, opens a valve to admit more. There is a *safety valve* in the boiler, which is loaded so as to open before danger can arise from the overheating of the water. The *rapidity of the combustion*, or force of the fire, is exactly regulated by the state of the boiler and wants of the machine: for there is a large open tube rising from near the bottom of the boiler through its top, to a height of several feet above it, and when the water is too hot, and the steam therefore too strong, water is pressed up into the tube, and by a float there, regulates the chimney valve or *damper;* on shutting it when there is too much heat, the draught is diminished and the fuel is saved, until a brisker fire is again wanted. In this figure, *a i g* marks the place of the *great beam* turning on an axis at *i*, through which the force of the piston is usually conveyed to the machinery to be moved. When the object is to raise water, the pump rods are connected with the end *g*; when any rotatory motion is wanted, the end *g* is made to turn a crank *l n* by the rod *g h*, and uniformity of motion is obtained by the influence of the great fly-wheel *m* fixed to the axis of the crank.

The simplest steam engine and the cheapest is that called the *high pressure engine.* In it steam of great force is used, as of 40 or 50lbs. or more to the inch; and while the fresh steam is pressing on one side of the piston, the steam which has worked is allowed to escape, or rather is driven out to the air from the other: the atmospheric resistance to the issue of the steam diminishes the working force of the piston just 15lbs. per inch. The simplicity of this form of engine recommends it; but the danger of having a large boiler of overheated water, like inflamed gunpowder, seeking to escape, has been proved so great, by numberless terrible accidents, that it is now only used in a few situations; and notwithstanding all the ingenious securites recently contrived against the danger, it is not now employed in England in a single passage-vessel.

In the low pressure engine, steam is never used of force exceeding 20lbs. on the inch, which being 5 lbs. only more than the atmospheric pressure, is insufficient to burst a boiler or to do mischief; but as the interior of the low pressure engine is kept in a state of vacuum, except where the steam is acting, the whole 20lbs. pressure is made available, and the engine has the same power, if of equal size, as a high pressure engine working with steam of 35lbs. on the inch. The required vacuum is preserved by means of a separate vessel or box c, called the condenser, into which cold water is constantly running to condense the steam, and is then pumped out again, with any little air that may have entered, by a pump represented at *k* in the figure. Steam on coming into contact with a cold body is condensed with the rapidity of an explosion.—The great merit of Mr. Watt was in the contrivance of this separate condenser, for, until his time, cold water had been thrown directly into the working cylinder, and cooled it so much, that twice or thrice its fill of steam was destroyed at each stroke to warm it again before it could work. This single change saved three-fourths of the fuel formerly expended.

Before Watt's day, the only steam engine in use was a rude *single-stroke engine*, as it was called, where steam pushed the piston up, and the pressure of the atmosphere pushed it down to do its work: on this last account it was also called an *atmospheric engine*. Such engines were only used for pumping water, and they wasted so much fuel, from the cause mentioned in the last paragraph, that the expense was not much less than that of horses.

In the atmospheric engine, the steam which lifted the piston against the atmospheric pressure required to be at least as strong as this to the very end of the stroke, Another of Watt's great improvements was, that by altogether excluding the air from his machine he was at liberty to stop the supply of steam for each stroke before the cylinder was full and to make the mere expansion of the quantity admitted impel the piston to the end of the stroke. This principle has been carried still farther by Messrs. Hornblower, Woolfe, and others, who have contrived double engines, in which strong steam is made first to act upon a small piston, and when it has finished a stroke there, it is admitted to a larger one, which it moves by its continued expansion alone. The same steam is thus made to do double work or more.

It might be supposed that high pressure engines would be wasteful, because in them the steam which has acted must be driven out of the cylinder against the powerful resistance of the atmosphere; while in the low pressure engine it passes away of itself to the condenser. But in the low pressure engine, nearly half the power of the steam is expended in overcoming the friction of the numerous parts and other impediments; while in that of high pressure the parts are so much fewer, and the piston is so much smaller in proportion to the force acting upon it, that the loss from friction is often less than a fourth, or even a sixth of the steam power, and thus, although the resistance of the air is to be overcome, there is often such a saving on the whole that, but for the danger attending a high pressure engine, it would generally be preferred.

From misapprehension of the law of increase of force by increase of heat in water, explained by the table at page 348, some exceedingly false conclusions have been drawn and acted upon at great expense, in attempts to make engines to work with an excessively high pressure. Perhaps a better proof could not be adduced of the absurdities into which even highly ingenious men may fall, when ignorant of the general truths of nature, or the scientific principles belonging to the branch of art in which they are labouring, than the history of supposed inventions and improvements connected with the steam engine.

The fertile genius of James Watt did not stop at the accomplishment of the two or three important particulars described above, but throughout the whole detail of the component parts and of the various applications of the engine he contrived miracles of simplicity and usefulness. It would exceed the prescribed bounds of this work to enter more minutely into the subject; but we may remark that, in the present perfect state of the engine, it appears almost a thing endowed with intelligence. It regulates with perfect accuracy and uniformity the *number of its strokes* in a given time, and it counts and records them as a clock does the beats of its pendulum;—it regulates the *quantity of steam* admitted to work;—the *briskness of the fire*;—the *supply of water* to the boiler;—the *supply of coals* to the fire;—it *opens and shuts its valves* with mathematical precision as to time and manner;—it *oils its joints*;—it *takes out any air* which may accidentally enter into parts that should be vacuous;—it *warns its attendants* by ringing a bell when any thing goes wrong which it cannot of itself rectify;—and with all these talents and qualities, and though it have the power of six hundred horses, it is obedient to the hand of a child;—its aliment is coal, wood, charcoal, or other combustible;—it consumes none while idle;—it never tires, and wants no sleep;—is not subject to malady when originally well made, and only refuses to work when worn out with age;—it is equally active in all climates, and will work at any thing;—it is a water-pumper, a miner, a sailor, a cotton-spinner, a weaver, a blacksmith, a miller—indeed, it is of all occupations: and a small engine in the character of a *steam pony* may be seen dragging after it on a rail-road ninety tons of merchandize, or a regiment of soldiers, with speed greater than that of our fleetest coaches. It is the king of machines, and a permanent realization of the *genii* of Eastern fable, whose supernatural powers were occasionally at the command of man.

It is no wonder that the inventor of an engine having such qualities as these, should receive the highest honours which his fellow-men could bestow. In November 1825, a public meeting was called to vote a monument to James Watt, then not long deceased; and the most distinguished men of the empire, of all parties, philosophers and statesmen, met to vie with each other in speaking his praise. Perhaps a series of such eloquent discourses have rarely been pronounced at one time, and perhaps in the progress of the arts of civilization there can rarely be offered such motive and occasion. The common voice of that distinguished assembly scarcely exaggerated, when it attributed to WATT's genius and perseverance that increase of our national commerce and of riches, which had enabled free Britain, single-handed, at an extraordinary crisis of human affairs, to contend with

Europe combined against her, and at last to triumph, so as to secure her own happy destinies, and probably much to influence those of the human race.

As science and the twin sister art are making constant advances, who shall say that even the steam engine, perfect as we have described it to be, is the limit to human discovery of obedient and yet mighty force. It is true that the nature of steam, and the laws of its formation and action, are now so well understood, that the intelligent engineer no more hopes for great improvement in steam engines, than he does in the mode of using a waterfall to turn a mill; but still there are kindred regions of nature left almost unexplored. We shall make a remark on this subject while considering the nature of *heat* in our next chapter.

The explosion of gunpowder and of all fulminating mixtures bears so strong an analogy to the phenomenon of the formation of steam, that the mind may advantageously contemplate the subject in this place.

The ingredients of which gunpowder is formed are chiefly substances which, when separate, exist at any common temperature in the form of air; and the combustion sets them loose with a production of intense heat, so as to produce an increase of volume which is instantaneous, and almost irresistible. By experiment and mathematical deduction, it appears that the exploding particles begin to separate from each other with a velocity as if ten thousand volumes of air had been condensed into one; and this explains the corresponding force and swiftness with which a bullet is propelled.

All the fulminating metals are chiefly combinations of the like substances with the metals, and they are held together by so slight a tie, that a little friction or elevation of temperature disunites them and produces an explosion.

The escape of the condensed air from the chamber of an air-gun, is a species of explosion: but is very gentle compared with the shock of discharged gunpowder.

It has lately been shewn that a gun-barrel may be connected with a high pressure steam boiler, as with a chamber of condensed air; and as the steam can be supplied as long as water remains in the boiler, if bullets be allowed to fall into the barrel fast enough, from a chamber or magazine above it, a hundred may be thrown out every minute with the same force and precision as if each issued from a common piece of artillery. The rapid succession may almost be said to resemble the issue of water from a jet pipe; and if such an engine could be used in a field of battle, the barrel of death, made to point gradually along a line of men, would mow them down like corn-stalks before the scythe—none could escape. The horrible idea and proposal have been excused by saying, that to prove the possibility of such havoc must have the effect of putting an end to war altogether.

The invention of gunpowder, with the consequent change of military tactics, from giving to a handful of men possessing it the mastery over thousands who had it not, was hailed by the philosophers of the day as a certain security against the relapse of civilized mankind into such a state of barbarism as followed the irruption into Europe of the Goths and Vandals: none but highly instructed and disciplined armies could now enter a European nation. This consideration, however, has lost its interest since the invention of printing, and other changes in society have given still better and more humane securities.

Besides the interesting instances now cited of the pressure of the atmosphere determining whether certain substances shall or shall not have the form of air, there are yet others that deserve mention, where the effect is modified by combination of bodies.

The pressure of the atmosphere at the surface of the earth keeps a certain quantity of air in combination with water, so that it forms part of the liquid mass. This air reappears at once on taking off the pressure. If we place a glass of water under the receiver of an air-pump and exhaust it, the glass is soon filled with bubbles of air, seen adhering all around on the sides, or rising through the water. This admixture of air in water is necessary to the life of fishes. It is driven off by boiling, and hence the vapid taste of water that has been boiled.

In making beer, wine, and other fermented liquors, there is a large quantity of the substance called carbonic acid formed during the fermentation. Much of it flies off in its usual form of gas, but much still remains in union with the liquid, because of the pressure of the atmospere. On removing this pressure suddenly the liquid appears almost to boil, as when a glass of warm beer is placed under the air-pump vacuum.

A degree of pressure still greater than that of the atmosphere, keeps a proportionally larger quantity of this carbonic acid in liquid combination: as in bottled porter or sparkling champaigne before the cork is drawn; but as soon as the compression maintained by the cork is removed, the gas escapes, causing the thin champaigne to sparkle, and the more viscid beer, which retains the little bubbles as they rise, to be covered with froth. After the sparkling and frothing have ceased under the atmospheric pressure, by placing the glass in the air-pump receiver the phenomenon may be renewed.

Carbonic acid so readily becomes liquid when the attraction of water is joined to compression, that enough of it may be united with water to make a pint become a pint and a half. The soda water, or aerated water, now so generally used in Europe as drink in warm weather, is water with carbonic acid forced into it by pressure, and a part of this is seen escaping always at the instant of the confining cork being drawn.

Carbonic acid forms one-fourth of the substance of marble or lime-stone; and when another stronger acid, as vinegar or sulphuric acid, is poured upon marble, it dispossesses the carbonic acid, and unites itself with the pure lime. The carbonic acid in rising constitutes the effervescence which then appears.

Many mineral waters contain carbonic acid, which remains in tranquil combination while the water is bearing a certain pressure under-ground; but which in part escapes as soon as only the atmospheric pressure remains; such waters are called sparkling waters.

The reason that champaigne and the aerated waters are so cool when first decanted is, that the carbonic acid, in assuming its gaseous form, absorbs as latent heat a large proportion of what was previously existing in the liquid.

The atmospheric pressure, by causing different densities in the air according to the different heights above the level of the sea, causes corresponding differences of temperature.

The explanation of this is simple. If a gallon of air at the surface of the earth contain a certain quantity of heat, this must be diffused equally through the space of the gallon; but if this gallon of air be compressed into one-tenth of the bulk, there will then be ten times as much heat in that tenth as there was before; and the increase will affect the thermometer. In like manner, if by taking off pressure the gallon be made to dilate to ten gallons, the heat will be in the same proportion diffused, and any one part will be proportionally colder than before. It is known that air may be so much compressed under the piston of a close syringe, that the heat in it similarly concentrated, becomes intense enough to inflame tinder attached to the bottom of the piston. This contrivance is in common use as a means of obtaining an instantaneous light.

Now, for the reason here explained, the air near the surface of the earth, forming the bottom of the atmosphere, because condensed by the weight of what is above it, is much warmer than the same air when higher up, where it is more expanded or thin, from the pressure being less. In many cases the height of mountains may be estimated by the difference of temperature observed at the bottom and at the top. While a thermometer stands at 60° at the bottom of St. Paul's Cathedral in London, another marks only 58° at the top of the dome; and in the lofty ascent of a balloon, the thermometer soon falls to the freezing point and below it, until the cold becomes almost insupportable to the aeronaut.

In every part of the earth there is a certain elevation in the atmosphere, differing according to the latitude or proximity to the equator, in which the thermometer never rises above the freezing point, and this limit is called the level of perpetual congelation. In Norway it is at five thousand feet above the level of the sea; in Switzerland at six thousand five hundred; in Spain and Italy at seven thousand; farther south, at Teneriffe, at nine thousand; directly under the sun, as in Central Africa and among the Andes in America, it is about fourteen thousand.

It appears, therefore, that the same low temperature may be found on the equator as at the pole, by rising to find it; and the snow-capt mountains are not the children only of high northern and southern latitudes. It is this truth which renders the tropical regions of the earth not only tolerable abodes in many parts, but inferior to none on earth; although, by reason of the great heat, the ancient philosophers of Europe thought them uninhabitable by man, and an everlasting barrier between the northern and southern hemispheres. Much of the central land of America near the tropics is so raised, that as to temperature it becomes a European climate, while the lightness and purity of air, and the brightness of sun, add delightfully to its charms. The mighty expanse of table-land forming the empire of Mexico is of this kind, enjoying the immediate proximity of the sun, and yet, by its elevation of seven thousand feet above the level of the ocean, possessing the most healthful freshness. The land in many parts has the fertility of a cultivated garden, and produces naturally all the treasures of vegetation scattered over the diversified face of the world. This country, well governed, might become a realization of paradise. The plains of Columbia in South America, and indeed all along the ridge of the Andes, are similarly circumstanced. It becomes a most singular contrast, after sailing one thousand miles up the level river Magdalena, in a heat scarcely equalled on the plains of India, all at once to quit the low region and climb to the table-land above, where *Santa Fé de Bogota*, the capital of the republic, is seen smiling over interminable plains, that bear the livery of the fairest fields of Europe.

Persons not reflecting on the law which we are now illustrating, have expressed surprise that wind or air blowing down upon them from a snow-clad mountain summit should still be warm and temperate. The truth is, that there is just as much heat combined with an ounce of air while on the mountain top as in the valley, but above, the heat is diffused through a space perhaps twice as great as it occupies below, and therefore is less sensible. It may be the same air which blows on a warm plain at the side of a mountain, which then rises and freezes water on the summit, and which in an hour or less after is again found among the flowers of another valley, as a gentle and warm breeze.

The temperature depending thus upon rarity of the air, gives a character to the vegetable productions of each distinct region or elevation, and many of the peculiarities of places and climate depend on it.

Because the atmospheric pressure determines the temperature of the air in different situations, as now explained, it has also a corresponding influence upon the state of aerial humidity, which is modified by the temperature.

It was explained at page 348, that water and other liquids enclosed in a vacuum rise in the form of air or vapour with force and in quantity having a strict relation to the temperature—heat being in fact the cause of their rising—and the table at page 348 exhibits the force, and therefore the density of watery vapour corresponding to some certain temperatures. Now it is a remarkable circumstance, that vapour of the same quantity and tension rises at a given temperature from any liquid, whether this be under the pressure of air or in a perfect vacuum, and it diffuses itself through any given space, among air of any density, just as if the air were not present. For a long time it was supposed that in such cases the air dissolved the liquid as a liquid dissolves a salt; but it now appears that there is merely a mechanical mixture of the two. If the vapour, while rising from a liquid, has not a tension or elastic force equal to the pressure of the atmosphere, the process is tranquil, and is called *evaporation*, and it goes on only as the vapour can diffuse itself among the particles of the air, and therefore slowly in air perfectly quiescent, but quicker as the air is moving more, or as the density of the air is less. But when the vapour, owing to greater heat, is strong enough to overcome the atmospheric pressure of fifteen pounds per inch, the phenomenon of boiling arises as already described.

For the reason now explained, the air of our atmosphere contains diffused through it a large quantity of invisible aeriform water; and if no changes of temperature happened in the atmosphere, the quantity of water would soon reach a *maximum*, or would be the greatest that the medium temperature of the earth could support, and then there would be no farther change: but instead of this, the local temperatures are constantly fluctuating, and when they fall in situations where a maximum of watery vapour is present, part of this is instantly reduced to the state of water again, and appears in the form of *mist*, *rain*, *snow*, or *hail*, according to circumstances. To supply material for these phenomena, evaporation is going on wherever, over water, there is not a *maximum* of vapour in the air: and these opposing operations of evaporation and condensation keep up that constant circulation of moisture which is the life of nature.

When a given quantity of water assumes the aeriform state, it contains the same quantity of latent heat in all cases, whether rising, for instance, from a steam engine boiler, or from the surface of a lake. Hence we see why evaporation is so cooling a process to a liquid or moistened solid from which it is arising; and as we have already shewn that a rapid passing of dry air, or a vacuum, quickens evaporation, we see now why both of these accelerate the cooling. Wet linen placed in a strong wind becomes dry almost immediately; a bottle of wine covered with a wet cloth and suspended in a current of air, as is practised in warm climates, is quickly cooled; mats hung up around the walls of houses in India, and frequently wetted through the day, preserve a delightful freshness in the apartments. The rapidity of evaporation from water under the exhausted receiver of an air-pump, and particularly when some other substance which powerfully absorbs watery vapour is included with it, is so rapid, and carries off the heat so quickly, that the mass of water freezes before much of it has been carried away. Sprinkling water or vinegar over a hot sick-room cools and refreshes it; and watering the streets of a city moderates there the intensity of summer heat. In warm climates water is cooled for drinking by putting it into vessels so porous that the external surface is always moist, the vessels being then suspended in a current of air, or when it is calm, being made to vibrate in the manner of a pendulum.

It is because air saturated with moisture, that is to say, having as much water diffused in it as can be supported in the invisible or aeriform state at the existing temperature, lets fall a part on any reduction of the temperature, that air which has been heated by the sun during the day, and has received much moisture, lets it fall again during the night, and exhibits the night fogs of certain seasons, which float upon the surface of the earth, until again acted upon by the beams of the next morning's sun. Fog more condensed, by groups of the particles uniting, forms rain; and this when cooled becomes snow or hail.

The quantity of dew which falls at night is much influenced by the moisture which the heat of the day enables the atmosphere to take up; but the immediate cause of the dew is, that the temperature of the objects on which it settles becomes lower during the night than that of the atmosphere. This true explanation was most ingeniously proposed some years ago by Dr. Wells. There is a tendency in heat to diffuse itself uniformly among bodies, by a constant radiation from one to another, which is rapid in proportion as the temperature of any one is higher, and it therefore soon reduces all to nearly the same state. Now when there are clouds in the atmosphere at night, they receive the heat darted upwards from the things on the earth's surface, and they radiate heat back in return, and become, as it were, a clothing to maintain the warmth of the earth beneath; and on cloudy nights there is no dew. But with a clear sky, the heat radiated upwards at night, darts into boundless space, and is lost altogether to the objects which emitted it. These, therefore, which during the day had the same, or even a higher temperature than the atmosphere around, now become colder, and the aeriform water which comes into contact with them is condensed, and forms a copious dew. This beautiful provision of nature supplies the necessary moisture to vegetables during seasons when rain is deficient. Dew on very cold objects freezes as it falls, and is then called *hoar frost*. A phenomenon which may class with that of dew is the perspiration, as it is vulgarly called, of massive walls and furniture on the sudden occurrence of warm weather; it is merely that the wall or other object, from not having yet acquired the temperature of the surrounding air, condenses upon itself a part of the atmospheric moisture.

Many instruments have been contrived, with the name of *hygrometers*, for indicating the quantity of water in the atmosphere. A prepared human hair is the essential part of one of the best: this lengthens or shortens according to the quantity of moisture around it; and its variation is made to move an index like that of a wheel barometer, to mark the degrees. The common hygrometers are only philosophical toys.

A great fall of the barometer indicates a diminished pressure in the atmosphere around, with a consequent dilatation of the air and fall of temperature, as explained a few pages back; and if the air at such a time hold a maximum of moisture, a part of it must fall. Thus a fall of the barometer, a fall of temperature, and a fall of rain, often come together as three adjoining links of a chain.

Illustrating this by experiment, we find, that on the extraction of air from the receiver of an air-pump, a cloud or mist often appears in it after the first strokes of the piston. The reason is, that the remaining air, cooled by the rarefication, absorbs heat from the vapour in combination with it, and renders this visible. It is then removed by the subsequent action of the machine, or is re-dissolved when the usual quantity of air is re-admitted.

We now understand why rain happens so much more frequently among mountains than on extended plains. If air saturated with moisture approaches a mountain ridge to rise over it, for every foot which it rises it escapes from a degree of the pressure which it bore while lower down, and in then dilating, it becomes colder, and lets fall part of its moisture. It is the rain periodically thus produced in mountainous regions which causes the extraordinary annual overflowing of many great rivers, such as the Nile, the Ganges, &c.

Those who have visited the Cape of Good Hope, will recollect a striking phenomenon illustrative of our present subject, observed there when the wind blows from the south-east. Beyond the city, as viewed from the bay, there is a mountain of great elevation, called, from its extended flat summit, the Table Mountain. In general its rugged steeps are seen rising in a clear sky; but when the south-east wind blows, the whole summit becomes enveloped in a cloud of singular density and beauty. The inhabitants call the phenomenon the spreading of the table-cloth. The cloud is composed of immense masses of fleecy whiteness. It does not appear to be at rest on the hill, but to be constantly rolling onward from the south-east; yet to the surprise of the beholder, it never descends, because the snowy wreaths seen falling over the precipice towards the town below, vanish completely before they reach it, while others are formed to replace them on the other side.—The reason of this phenomenon is, that the air constituting the wind from the south-east having passed over the vast southern ocean, comes charged with as much invisible moisture as its temperature can sustain. In rising up the side of the mountain it is rising in the atmosphere, and is therefore gradually escaping from a part of the former pressure; and on attaining the summit it has dilated so much, and has consequently become so much colder, that it lets go part of its moisture. This then appears as the cloud now described; but its substance no sooner falls over the edge of the mountain, and again descends in the atmosphere to where it is pressed, and condensed, and heated as before, than the water is re-dissolved and disappears: thus the magnificent apparition dwells only on the mountain top.

When the elevation to which moisture is suddenly carried is very great, the fall of temperature is proportional, and the separating water becomes snow instead of rain. In a *Hero's* fountain, used in one of the mines of Hungary, the air is so compressed, that on being released, it expands and cools enough to cause the moisture driven out with it to appear immediately, even in summer, as a shower of snow.

The foregoing reasoning explains why along the sides of mountain ridges, clouds are generally seen floating at a certain height only, and therefore in horizontal strata. The water is separated from the air at a certain temperature, which is dependent on the height, as explained at page 364; and above that height the air is too rare to support clouds. Very lofty summits are seen rising above the clouds altogether, and the admirer of nature who climbs towards them may see the grand phenomena of the thunder-storm far beneath his feet. Teneriffe soars so sublimely, that the distant sailor often mistakes the line of clouds hanging around its sides for the white streak which elsewhere indicates the cliffs and waves of the sea-shore.

Fluid support or floating, in air. (Read the analysis, page 285.)

When it was explained, under "Hydrostatics," that any body immersed in a fluid is resisted or held up exactly with the force which would support a quantity of the fluid occupying the same space, and that therefore the body will sink or swim, according as it is heavier or lighter than its bulk of the fluid, the reasoning was as applicable to the case of a body immersed in an air as in a liquid.

We hence see why a body weighed in air appears lighter than when weighed in an empty space or vacuum, by the exact weight of its bulk of the air:—and why, for the same reason, the jocular question, whether a pound of lead or a pound of cork be the heavier, admits of a more profound answer than is usually supposed. The cork is really the heavier, because when balanced in air, bulky cork is more supported than denser lead. A small beam, with pieces of cork and lead which equipoise in the air, attached to its opposite ends, if placed under the exhausted receiver of an air pump, exhibits the cork preponderating.

As any liquid lighter than water, such as oil or spirits, on being set at liberty under the surface of water, will rise, while any heavier liquid, such as brine, syrup, or sulphuric acid, will sink; and in both cases with force proportioned to the difference of specific gravities—so we find, that in common air, a mass of hydrogen or hotter air ascends, because specifically lighter; while oxygen, carbonic acid gas, or colder air descends, because specifically heavier.

A Balloon

is a thin light bag of varnished silk, generally shaped like a globe or egg, and filled with a fluid lighter than common air. It is made large enough to enable it, by the difference between its weight and that of an equal bulk of common air, to carry aloft the material of which itself and its car are constructed, with the aeronauts, and their apparatus. It is in principle like a bladder of oil immersed in water. A globe of thirty-five feet diameter has a capacity of nearly twenty-two thousand cubic feet. This quantity of common air weighs about *sixteen* hundred pounds, and the same quantity of hydrogen gas, of easily obtained purity, weighs only one-eighth as much, or *two* hundred pounds. Such a globe, therefore, being buoyed up, or supported in common air, with a force of sixteen hundred pounds, while, if filled with hydrogen, it only weighs two hundred, will carry up into the sky fourteen hundred pounds of material and load.

The first balloon was constructed by a man ignorant of what he really was effecting. Seeing the clouds float high in the atmosphere, he thought that if he could make a cloud, and enclose it in a bag, it might rise and carry him with it. Then erroneously deeming smoke and a cloud the same thing, he made a fire of green wood, and placed a great bag over it with the mouth downwards to receive the smoke. He soon had the joy of seeing this full, and ascending; but he understood not that the cause was the hot air within, which, being heated and dilated, became lighter than the surrounding air, and was buoyed up, while the visible part of the smoke, of which he chiefly thought, was really heavier than the air, and was an impediment to his wishes.

The true principle of the *hot air or fire balloon* was afterwards better understood, and the contrivance was used by aeronauts, until the more commodious and less dangerous modification, called the *inflammable air balloon*, or balloon of hydrogen, was substituted.

Since the modern introduction of gas lights, the *carburetted* hydrogen used for them is generally employed for filling balloons. It is considerably heavier than pure hydrogen, but is so much more readily obtained, that aeronauts prefer making a larger balloon to suit it, than a smaller one which obliges them to prepare the other. A thin paper bag, filled with the hot air rising from a large lamp, is a miniature *hot air or fire balloon;* and a common soap bubble filled with hydrogen, is a little *inflammable air balloon*, which mounts with great rapidity.

There are, perhaps, few occasions calculated more to surprise and delight the mind, than when a balloon is first beheld sailing high in the bosom of the air, and lifting man to regions far beyond those which the soaring eagle has ever reached; and to the intrepid aeronaut himself, the scene of a world displayed beneath him is unquestionably the grandest which mortal eye has ever compassed. Even wide-spread London, the queen of the cities of the earth, and a little world within itself, when viewed from such an elevation in the sky, appears but as a dusky patch upon a map, where the far-famed Thames is seen winding as a silvery line, and where the magnificent temples and palaces scattered around, appear but as darker points rising out of the general mist of buildings, in which a million and a half of human beings reside.

The first aeronautic expeditions astonished the world, and endless reveries passed through mens' minds of important uses to which the new discovery might be applied; but more mature reflection, and now frequent trials, have shewn, that the balloon is interesting chiefly from having furnished philosophers with the opportunity of making important observations in elevated regions of the atmosphere. The French, under the Directory in 1796, attempted to use it as a military station, from which the position and motions of an enemy might be descried; but the plan was eventually abandoned. Although aeronauts, while aloft, have the power of making the balloon rise farther by throwing out part of the sand ballast which they carry with them, or descend by opening a valve at the top of the balloon which allows the hydrogen to escape, still they have no power of producing a lateral motion. The idea which yet strongly excites the minds of some projectors, that means may be found of directing a balloon in the sky, as a ship is directed on the sea, is about as reasonable as to suppose that a little worm, suspended to a huge block of wood, and driven along at the rate of eight or ten miles an hour by a river torrent, should have power to stop or sail against the current. A man in a balloon would generally have to resist or change a motion of seventy or eighty miles an hour.

A balloon which is only half full at the surface of the earth, will be quite full when it has risen three miles and a half, because at that altitude, air from below doubles its volume on account of the diminished pressure. A balloon, therefore, if quite distended on first rising, must let out as it ascends, or it will burst: this is true also of the drum of the human ear under the same circumstances, and in a contrary way under the opposite circumstances, of descending in a diving bell.

The downy seeds of plants which are seen floating about upon the wind in autumn, are not lighter than air, but have so much bulk and surface in proportion to their weight, that the friction of the passing air upon them is greater than their weight, and carries them along.

A sheet of paper, made in some degree to resemble a balloon, from having a little weight representing the car attached under it by threads from the angles, is often seen rising at a street corner, to the delight of the boy who watches it. Its rise depends upon eddy winds or currents which the corner produces.

The ascent of flame and smoke

in our atmosphere, affords other examples of a lighter fluid rising in a heavier; for both these are merely hotter air rising in the midst of colder air. The phenomenon of flame is produced when the burning substance contains some ingredient capable of assuming the form of air on being heated, and which on ascending, burns or combines with the oxygen of the atmosphere, with intensity of action sufficient to produce a white heat. It is because charcoal and coke have nothing volatile in them, that they burn without flame or smoke, appearing like red-hot stones. The flame of a lamp or candle is merely the carburetted hydrogen of the oil, wax, or tallow, allowed to burn as it is disengaged and rises. The same gas is obtained by heating the oil, &c. in vessels which exclude the atmosphere, and prevent immediate combustion, and then it is the common oil gas used for illumination.

Smoke consists of all the dust and visible particles which are separated from the fuel without being burned, and are light and minute enough to be carried aloft by the rising current of heated air; but all that is visible of smoke is really heavier than air, and soon falls again as powdered chalk does in water. In the receiver of an air pump, where a candle has been extinguished by exhausting the air, the stream of smoke that continues to pour from the wick after the exhaustion, is seen to fall on the pump plate, because there is no air to lift it.

Chimnies quicken the ascent of hot air by keeping a large quantity of it together. A column of two feet high rises with twice as much force as a column of one foot, and so in proportion for all other lengths; just as two or more corks strung together, and immersed in water, tend upwards with more force than a single cork; or as a long spear of light wood, allowed to ascend perpendicularly from a great depth in water, acquires a velocity which makes it dart high above the surface, while a short piece of it under the same circumstances rises very slowly. In a chimney, one foot in height of the column of hot air, may be one ounce lighter than the same bulk of the external cold air; and if the chimney be one hundred feet high, the air or smoke in it is propelled upwards with a force of one hundred ounces. In all cases, therefore, the *draught*, as it is called, of a chimney, is proportioned to its length. The following facts are consequences of this truth.

In low cottages, and in the upper floors of houses, the annoyance of smoke in the rooms is much more frequent than where chimnies are longer.

If there are two fires in the same room, or in any rooms open to each other, having chimnies of different lengths, if the doors and windows are very close, so that air to supply the draughts cannot enter by them, the taller chimney will overpower the shorter, and cause it to smoke into the room; just as the long leg of a syphon overcomes the short one, or as a log of wood, held down in water by a cord passing from it round a pully at the bottom, to a shorter log also floating, will rise, and pull down the shorter log.

A long chimney, for the reasons now explained, causes a current of air to pass through the fire very rapidly, and more uniformly than any bellows or blowing machine, and therefore, for steam engine fires, and many others, it is the means of blowing generally preferred. The most intense heat that art can produce in a furnace is in that called an air furnace, that is to say, in one blown by the action of a chimney. The importance of length in a chimney explains the singular appearance of some modern English towns, where steam engines abound.

When we heap dying embers together, so that the hot air rising among them may become a column of some elevation, this column has the effect of blowing them gently, and helps to light them up again.

The action or draught of a chimney depends also on the degree in which the air in it is heated, because this determines the dilatation or lightness, which makes the air ascend.

In what are called *open fire-places*, such as those in the sitting rooms of Britain, a large quantity of colder air directly from the apartment enters the chimney above the fire, and mixes with the hot air from the fire itself. This mixture ascends more slowly than if the hot air alone entered, in exact proportion to the degree of mixture. The effect of excluding a part of this cold air, is seen when a board or plate of metal is applied across the opening of the chimney, so as to narrow the entrance: almost instantly a quicker action is produced, and the fire burns as if blown by a bellows. This means is often used to cure a smoky chimney, by increasing the draught, and to blow the fire instead of bellows. What is called a *register stove* is a kindred contrivance. Its chief peculiarity is a flap placed in the throat of the chimney, serving to widen or contract this at pleasure; and because generally opened only enough to allow that air to pass which rises directly from the fire, the chimney receives only very hot air, and therefore acts well. The register stove often cures smoky chimnies; and by preventing the escape of the moderately warmed air of the room, of which so much is wasted in a common fire-place, it also saves fuel. In what are called close fire-places, as those of steam engines, or brewers' coppers, when the furnace door is shut, no air can enter the chimney but directly through the fire: hence the action of such chimnies is very powerful.

In a room with two fires, or in drawing-rooms communicating with each other, although the chimnies be of equal length, that one over the best fire will act most strongly; and if the doors and windows be so close, that sufficient air cannot enter by them to supply both chimnies, cold air will enter by that one where the weakest fire is, and the smoke from it will spread into the room. How often is a meeting dinner party annoyed by the smoke of a back drawing-room fire which had just been lighted before their arrival, and which had therefore to contend with the other chimney, already in powerful action all the day. In such a case, while only one fire is lighted, the cold chimney admits the air to feed it, just as an open pane in the window would do. A room may be so close that air cannot find entrance; in such a case the smoke of a fire there must flow into the room.

If all the windows and doors of a house fit so well as not to admit air for the acting chimnies, the supply comes down the chimnies that are not in use. From inattention to this fact many a good chimney gets the reputation of being smoky, because on attempting to light a fire in it the smoke at first is always thrown back. The truth is, that when the servant begins to light the fire, there is a downward current in the chimney, which repels, of course, any heated air or smoke that approaches it, and spreads them over the whole house; but were the servant to shut the room door for a few minutes, so as to cut off communication with the other *drawing* chimnies in the house, and at the same time to open the window, the chimney would act at once; and when sufficiently heated, would continue to act in spite of the others, and as well.

There are some cases of smoky rooms which are not so easily corrected as those which we have now mentioned. When a low house stands near a lofty one, the wind being obstructed by the latter, becomes a gathering or condensation of air against the wall; and if the top of a low chimney be there, the compressed air enters it, and pours downwards. The same happens occasionally from the proximity of trees or rocks. In such cases, to avoid the influence, chimnies are often made very lofty. Again, whenever from the nature of buildings, eddies of wind occur, as at street corners, &c., chimnies do not act regularly. It is proverbial, that corner houses, or those at the ends of a row, are smoky houses, and the uniformity of architecture is often destroyed by the necessity of lengthening their chimnies. Smoke is often found descending into a room where there is no fire, when the empty chimney is serving as an inlet for air to the house, and the smoke of a neighbouring chimney is passing closely over the top of it.

In summer, when fires are not in use, there is often a strong smell of soot perceived in the apartments during the whole of the day, but which ceases at night. The reason is, that during the day the chimney is colder than the external air; and by condensing the air which enters, it causes a downward current through the soot. During the night, again, when the external air becomes much colder owing to the absence of the sun, the chimney is hot enough to warm what enters, and to cause an upward current. These currents in chimnies left open during the days and nights of summer, are almost as regular as the land and sea breezes of tropical countries.

All these remarks prove how important it is to be able to conceive clearly of the motions going on, according to the simple laws of matter, in the invisible air around us. Were such subjects better and more generally understood, many prevalent errors in the arts of life would soon be corrected, and we should have a corresponding improvement in the comforts and health of the community. We are filled with admiration on discovering how perfectly the simple fact of a lighter fluid rising in a heavier, provides a constantly renewed supply of fresh air to our fires, which supply we should else have to furnish by the unremitted action of some blowing apparatus; but the operation of the law is still more admirable as respects the supply of the same vital fluid to breathing creatures. The air which a man has once respired becomes poison to him; but, because the temperature of his body is higher than that of the atmosphere around him, as soon as he has discharged from the lungs what has once served, it ascends away from him to the great purifying laboratory of the atmosphere, and new air takes its place. No art or labour of his could have done half so well what this simple law unceasingly and invisibly accomplishes, and without effort or attention on his part; and in his sleeping as well as in his waking hours.

The warming and ventilating of houses

is an important art, founded chiefly on the foregoing considerations, and at present too little understood, not only by the public at large, but even by medical practitioners, whose management of disease, though judicious in other respects, is often rendered vain by error or omission in this.

Excellent fuel is so cheap in Britain, owing to the profusion with which beds of rich coal are scattered among the mineral treasures of this favoured portion of the earth, that a careless expenditure has arisen; which, however, instead of securing the comfort and health that might be expected, has led to plans of warming that often prove destructive of both. In cold countries, where fuel is more scarce, as in the north of continental Europe, and where, to retain and preserve the heat once obtained, the inhabitants use thick walls, double windows, close joinings and close stoves or fire-places, which have no communication with the apartments, but draw their supply of air from without, that the temperate air of the room may not be wasted,—these means, when sufficient ventilation is added, prove very favourable to health, by giving a uniform and temperate warmth, instead of extremes and fluctuations. But in England, the apartments, with their open chimnies, may be compared to great aerial funnels, constantly pouring out their warm air through a large opening, and constantly requiring to be replenished; and where, from the irregularity of the supply or of the discharge, the temperature is constantly fluctuating.

By the close stove and apartment fuel is saved to a great extent—they also produce a uniformity of temperature; first, as regards the different parts of the room, so that the occupiers may sit any where; and secondly, as regards the different times of the day; for the stove once heated in the morning, often suffices to maintain a steady warmth until night: the heat can be carried to any required degree, and ventilation is easily effected as desired.

The open fire-place, again, wastes fuel exceedingly, because the chimney being large enough to allow a whole room full of air to pass away by it in two or three minutes, the air of the room has to be warmed, not once, but very many times in the course of the day.—The temperature is made to fluctuate by the slightest causes, as the opening a door, the omitting to stir the fire, &c.—The heat is very unequal in different parts of the room, rendering it necessary in general for the company to sit near the fire; and there they must often submit to be almost scorched on one side, while they are chilly on the other.—There is generally a warm stratum of air above the level of the chimney-piece, surrounding, therefore, the upper part of the bodies of those in the room, while a cold stratum below this envelops the sensitive feet and legs.—As a very rapid current is constantly ascending in the chimney, a corresponding supply must be entering somewhere; and this arrives by the crevices and defects in the doors, windows, floors, &c. Now there is nothing more dangerous to health than to sit near such inlets, as is proved by the rheumatisms, stiff necks, and catarrhs, not to mention more serious diseases, which so frequently follow the exposure. There is an old Spanish proverb, thus translated,

> "If cold wind reach you through a hole,
> Go make your will, and mind your soul."

which is scarcely an exaggeration.

Consumption is the disease which carries off a fifth or more of the persons born in Britain, owing in part, no doubt, to the changeableness of the climate, but much more to the faulty modes of warming and ventilating the houses. To judge of the influence of temperature in producing this disease, we may consider—that miners who live under ground, and are always, therefore, in the same temperature, are strangers to it; while their brothers and relations, exposed to the vicissitudes of the weather above, fall victims—that butchers and others who live almost constantly in the open air, and are hardened by the exposure, enjoy nearly equal immunity—that consumption is hardly known in Russia, where *close* stoves and houses preserve a uniform temperature—and that in all countries and situations, whether tropical, temperate, or polar, the frequency of the disease bears relation to the frequency of change. We may here remark also, that it is not consumption alone which springs from changes of temperature, but a great proportion of acute diseases, and particularly of our common winter diseases. In how many cases has the invalid to remark, that if he had not taken cold in such a place, or on such an occasion, he might yet have been well.

While temperature is thus so frequently an original cause of disease, it is also a circumstance of the very highest importance in the treatment, as is proved, by every fact bearing upon the question. It may, therefore, at first seem extraordinary, that it should be so negligently and unskillfully controlled as we often see it, and that disease and death should be allowed thus to lurk almost undisturbed in the sanctuaries of our homes; but when we reflect on the subtile and invisible nature of air and heat, and that the science which detects their agencies has been hitherto so little an object of general study, and indeed is of modern discovery, the fact is accounted for.

In England, the open fire-place for common dwellings is so generally in use, and the cheerful blaze is thought so essential to the happiness of our winter days and long evenings, that it would be difficult to persuade to the abandonment of it;—and perhaps, when the subjects which we are now discussing come to be better and more generally understood, it will be found that, with close flooring, and better or double windows, and doors that fit well, and register stoves, and good general management, the open fire may be rendered almost as efficient for warming, and as safe to health, as any other contrivance.

The following considerations present themselves in this place.—Small rooms in winter are more dangerous to health than large ones, because the cold air, entering towards the fire by the doors or windows, reaches persons before it can be tempered by mixing with the warmer air of the room.—Stoves in the halls and staircases are useful, because they warm the air before it enters the rooms; and they prevent the hurtful chills often felt on passing through a cold staircase from one warm room to another.—It is important to admit no more cold air into the house than is just required for the fires, and for ventilation; hence there is great error in the common practice of leaving all the chimnies that are not in use, quite open; for each admits as much air as a hole in the wall would do, or a pane deficient in a window.—Perhaps the best mode of admitting air to feed the fires is through tubes, leading directly from the outer air to the fire-place, and provided with what are called throttle valves, for the regulation of the quantity: or the fresh air admitted by tubes may be made first to spread in the room, having been warmed during its passage inwards, by coming near the fire.—In a perfectly close apartment, ventilation must be expressly provided for by an opening near the ceiling, to allow the impure air rising from the respiration of the company to pass away at once; but with an open fire, the purpose is effected by the frequent change of the whole air of the room which that construction occasions.

With a view to have the most perfect security against cold blasts and fluctuation of temperature in rooms intended for invalids, and still to retain the so much valued appearance of the open fire, a glazed frame or window may be placed at the entrance to the chimney, so as completely to prevent the passage of air from the room to the fire. The close room will then be warmed by the fire through the glass, as a green-house is warmed by the rays of the sun. It is true, that the heat of combustion does not pass through glass so readily as the heat of the sun; but the difference is not important. The glass of such a window must, of course, be divided into small panes, and supported by a metallic frame-work; and there must be a flap or door in the frame-work, for the purposes of admitting the fuel and stirring the fire. Air must be supplied to the fire as described above, by a tube leading directly from the external atmosphere. The ventilation of the room may be effected by an opening into the chimney near the ceiling; and the temperature may be regulated with great precision by a valve placed in this opening, and made to obey the dilatation and contraction of a piece of wire affixed to it, the exact length of which at any time will depend on the temperature of the room.—The author first imagined such an arrangement of rooms for the winter residence of a person who was threatened with consumption; and the happy issue of the case, and of others treated on similar principles, has led him to doubt, whether many of the patients with incipient consumption, who are usually sent to warmer climates, and who die there after hardships on the journey, and mental distress from the banishment sufficient to shake even strong health, might not be saved, by judicious treatment in properly warmed and ventilated apartments, under their own roofs, and in the midst of affectionate kindred.—And if a boy be almost certainly secured from consumption by becoming a miner or a butcher, may we not hope that, when all the influencing circumstances come to be better understood, something of the same immunity may be obtained for persons in all the professions and conditions of civilized society?

It must not be supposed that the remarks made in this section go near to exhaust the very important subject of temperature as affecting health. The questions of *clothing*, of *hot and cold bathing*, of *exercise*, and others, equally belong to it, but the consideration of them falls under other departments.

Winds or currents in the atmosphere

are also phenomena, in a great measure dependent on the law of lighter fluids rising in heavier ones. As oil let loose under water is pressed up to the surface and swims, so air when heated by the sun, is raised to the top of the atmosphere, and spreads there, while the heavier air around rushes inwards, and constitutes wind. The cross currents in the atmosphere are often rendered evident by the motion of clouds or balloons.

If our globe were at rest, and the sun were always acting directly over the same part, the earth and air under him would become exceedingly heated, and the air would be constantly rising like oil in water, or like the smoke from a great fire; while there would be currents or winds in all directions below, towards the central spot. But the earth is constantly whirling under the sun, so that the whole equatorial belt may be called the sun's place; and therefore, according to the principle just laid down, there should be a constant rising of air over this belt, and constant currents from the two sides of it, or the north and south, to supply the ascent. Now this phenomenon is really going on, and has been going on since the beginning of the world, producing the steady winds of the northern and southern hemispheres, called *trade winds*, on which mariners reckon almost as they do on the rising and setting of the sun himself. These winds, however, do not appear on the earth to be directly north and south, as they are in fact, because its eastward whirling or diurnal rotation, causes a wind from the north to appear as coming from the north-east, and a wind from the south as coming from the south-east: just as to a man on a galloping horse, a calm appears to be a strong wind in his face, and if he be riding eastward in a north or south wind, such will appear to him to come from the north-east or south-east.

Thus also, if a small globe be made to turn upon a perpendicular axis, and a ball be allowed to roll from the top of it downwards, or a little water be poured in the same direction, the ball or water will not immediately acquire the whirling motion of the globe, but will fall almost directly downwards; and if the track be marked upon the globe, it will not appear as a direct line from north to south, but as falling obliquely; and if the globe be moved in the direction of our earth, the line will be from north-east to south-west.—It is thus the whirling of the earth which causes the oblique and westward direction of the trade winds, and not, as has often been said, the sun drawing them after him.

Beyond the tropics, where the heating influence of the sun is less, the winds occasionally obey other causes, which have not as yet been fully investigated. They are hence much less regular, and are called *variable*. But still as a general rule, whenever air is coming from the north or south poles where it was at rest, it must for a time have the appearance of an east wind, or a wind moving in the contrary direction to the earth itself, until it has gradually acquired the whirling motion of that part of the surface of the earth on which it is found; and again, when air is moving from the equator, where it had at last acquired nearly the same motion as the earth, on reaching parts nearer the poles, and which have less eastward motion, it continues to run faster than these parts, and becomes a west wind. North of the equator, therefore, on earth, true north winds appear north-east, and true south winds appear south-west;—and these are the two winds which blow in England for three hundred days of every year. In southern climates the converse is true.

While the sun is beaming directly over a tropical island he warms very much the surface of the soil, and the air over it, while the rays which fall upon the ocean around penetrate deep into the mass, and are there absorbed. The consequence is, that there is a rapid ascent of air over the island during the day, and a cool wind blowing towards its centre from all directions. This wind constitutes the refreshing *sea-breeze* of tropical islands and coasts. One must have been among these to conceive the delight which the sea-breeze brings after the sultry stagnation which precedes it. The welcome ripple shorewards is first perceived on the surface of a glassy or perfectly smooth water; and soon the whole face of the sea is whitened with little curling waves, among which the graceful canoe shoots swiftly along.

During the night an opposite phenomenon takes place. The surface of the earth, now no longer receiving the sun's rays, is soon cooled, while the sea which was heated in the day, not on the surface only, but through its whole mass, continues to give out heat all night. The consequence is, that the air over the earth being colder than that over the sea, sinks down, and spreads out on all sides, and becomes the *land-breeze* of tropical climates. This wind is often charged with unhealthly exhalations from the marshes and forests, while the sea-breeze is all purity and freshness. Many islands and coasts would be absolutely uninhabitable but for the latter.

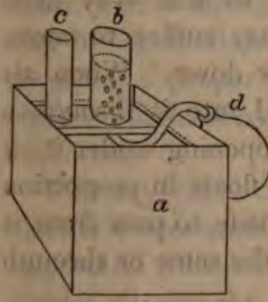
The unequal distribution of land in the eastern part of the globe, has produced the curious effect there of a sea-breeze of six months, and a land-breeze of six months. The great continent of Asia is chiefly north of the line, and during its summer the air over it is so much heated, that there is a constant steady influx from the south (appearing south-west, for the reason given in the last page); and during its winter months, while the sun is over the southern ocean, there is a constant land-breeze from the north (appearing, for a like reason, north-east). These winds are called *monsoons;* and if their utility to commerce were to be a reason for a name, they also deserve the name of trade winds. In early periods of navigation, these winds served to the mariner the purpose of compass, as well as of moving power; and one voyage outward, and another homeward, with the changing monsoons, filled up the year.

The frightful tornadoes, or whirlwinds, which sometimes devastate whole regions, and make victims of every ship or bark caught on the waters, and the sudden gusts or squalls met with everywhere, are owing to some sudden chemical changes in the atmosphere, which are not yet fully understood.

The Pneumatic trough and gasometer

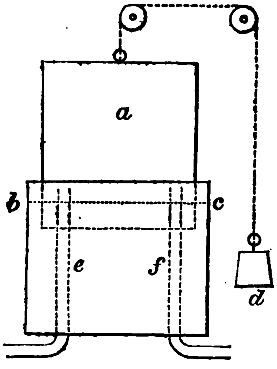
of the chemist, are contrivances founded on the law now under consideration, that a lighter fluid is pushed up or floats in a heavier. They are the chief parts of his apparatus for operating on the different substances while in the form of air.

A trough *a* may be made of tin plate or wood, and of any convenient size. It is nearly filled with water, and has at one end, a little under the surface of the water, a shelf, on which jars or vessels, as *b* and *c* may rest. Any particular air or gas may be preserved separate from the atmosphere, by being placed in one of these jars with the mouth downwards. It may be passed into the jar by first immersing this in the trough, so as to fill it with water and to expel the common air from it; and by then holding the mouth over the air or gas as it rises under the water from another vessel or pipe. *d* represents a long-necked vessel, used for the production of gases by chemical action. The gas of course rises to the top of the jar *b*, and gradually displaces the water. During



the operation of filling, the jar may be resting upon the shelf with only the mouth immersed, and then the air may be allowed to rise into it through a hole in the shelf, provided with a small funnel opening downwards to catch the air more readily. On the shelf there may be room for many jars, and it may have more holes than one; and if the gas under operation be one which water absorbs or changes, some other liquid, as mercury, may be used instead of water.

A *gasometer or gas-holder*, is merely a larger jar or vessel *a*, with its mouth downwards in water, in a trough of its own shape, *b c*, just large enough to receive it, and the vessel being supported or counterpoised by a weight *d*, over pullies, so that very little force may suffice to move it up or down. When air is forced into it through a pipe *f* opening under it, it rises or floats in proportion to the quantity. The air is made to pass from it again when wanted, through the same or through another tube, as *e*.



The huge gasometers, exceeding in size an ordinary house, which contain the supply of gas for the lamps of a town, are vessels suspended in this manner, in great pits, or in troughs constructed of pieces of cast-iron, and filled with water. The gas issues with force proportioned to the downward pressure of the containing vessels, which is very nicely regulated in a variety of ways, and generally so as to be equal to the action of a column of water of two inches in height.

It would be encroaching on the province of the chemist to describe here particularly the substances which most usually exist in the aeriform state; but to give an increased interest to this description of gas apparatus, a few leading facts may be mentioned.

The water used to fill the apparatus is a compound of two substances, which in their uncombined state, and under common circumstances of heat and pressure, exist as airs or gases. These are *oxygen* and *hydrogen*. By directing an electrical current through water, it is gradually decomposed, and from one end of a tube a stream of aeriform oxygen may be received, and from the other end a stream of hydrogen. These gases may be again united to form water, by mixing them in a proper vessel, and then passing an electric spark through them. They combine with explosion.

This *oxygen*, so called from its relation to acids, has been accounted, for many reasons, the most important substance in nature. It forms eight-ninths, by weight, of the ocean; one-fourth of the atmosphere; and, perhaps, one-fourth of the solid matter of the globe; and possibly, therefore, there is not a millionth part of the quantity of oxygen in the world, existing as air. It unites readily with most other substances, and generally with such intense action as to produce the phenomenon of fire or combustion;—the word *combus-*

tible chiefly applies to a substance that will quickly combine with oxygen.

Oxygen singularly changes the character of the things with which it combines. Thus with *hydrogen*, it forms water; with *lead*, it forms the substance called *red-lead;* with *nitrogen*, in one proportion, it forms *atmospheric air;* in another proportion, the nitrous oxide, or what is called the *laughing gas;* in a third, the acid called *aquafortis;* with sulphur, it forms the *sulphuric acid* or *oil of vitriol;* with iron, and all metals, it forms their ores called oxides; and so forth. But the most important character by far in which it appears, is as that ingredient of our atmosphere, without which animals and vegetables cannot live, and fire cannot burn. Oxygen was long named *vital* or *pure air*.

Pure oxygen in the state of air is a little heavier than common air; but when combined with charcoal, it forms the aeriform carbonic acid, which is twice as heavy as common air, and may be poured out of one vessel into another like water. This is what issues from soda-water, brisk ale, champaigne, &c. If drawn into the lungs in breathing, it is fatal to life. A charcoal fire left in a close room with sleeping persons, often kills them, because carbonic acid gas is the product of the combustion. The famous *Grotto del Cane* in Italy, is a cavern always full of carbonic acid, which springs into it from below, as water springs into a well, and runs over like water from a well. It received its name from dogs being thrown into it to die. Carbonic acid rising in fermentation has often proved fatal to persons leaning over the edge of fermenting vats. It is common to see a rat die instantly, in the attempt to run along a plank that lies across the mouth of a fermenting tub.

Hydrogen, the other ingredient of water, and so called from its relation to water, when in the state of air, is nearly fifteen times lighter than oxygen: with it balloons are filled. By dissolving a certain quantity of carbon or charcoal, it becomes the common gas used for illumination: it is the fire-damp of mines, of which the burning and explosion is so terrible. It forms one-ninth of the ocean, and much of animal and vegetable bodies; and probably a little of it floats separately in the higher regions of the atmosphere.

Nitrogen, so called from its relation to nitric acid, is the third and last substance which we shall mention. It is what remains of the atmosphere when the oxygen is removed. It forms about three-fourths of the atmosphere, one-fourth of animal flesh, and is found in small quantities in other combinations. It will not support life by itself, and therefore formerly was called *azote:* with a larger proportion of oxygen it forms *nitric acid*, or the *aquafortis* of old.

The last few paragraphs shew how completely the performance of the manipulations of chemistry is founded upon physics or mechanical philosophy, and therefore how essential to the chemist the preliminary study of physics becomes.

CHAPTER III.

DOCTRINE OF FLUIDS.

SECTION III.—HYDRAULICS—PHENOMENA OF FLUIDS IN MOTION.

ANALYSIS OF THE SECTION.

Whether the particles of matter exist in the form of solid or fluid, the circumstance does not at all affect their properties of INERTIA *and* GRAVITY. *Hence liquids and airs, in proportion to their quantity, resist, receive, and impart motion, and have gravity, just as is true of solids. This is proved by the phenomena of*

1. *Fluids moving in pipes and channels, or issuing from them.*
2. *Waves.*
3. *Fluids resisting the motion of bodies immersed in them; or themselves moving against other bodies.*
4. *Fluids lifted or moved in opposition to gravity.*

"*Fluids moving in channels or issuing from them.*"

WATER in a tube, connected with a reservoir, will rise to the level of the liquid surface in the reservoir. If the tube be then cut off, except a small part at the bottom, left and prepared as a jet pipe, the water will spout from this, still to the same height. Now, as a body shot upwards has the same velocity in departing which it again acquires by falling to the same place (with a little correction for the resistance of the air), it appears that fluids issue from orifices with the velocity in each case which a body acquires in falling as far as from the surface in the reservoir to the orifice. By referring then to the law of falling bodies, as explained at page 80, we learn the velocity of the issue of water in any case, and therefore the quantity delivered by an opening of a given magnitude. A body by gravity falls sixteen feet in the first second, and at the end of this has a velocity of thirty-two feet per second. Therefore a reservoir with an opening of an inch square, at sixteen feet below the water's surface, will deliver thirty-two cubic inches in one second of time, (with a certain deduction for friction); and according to the same rule, an opening at four times the depth should deliver a double quantity; at nine times the depth, a triple quantity; and so on; as really happens. At first, an inquirer is surprised that the quantity should not be quadruple, where the pressure forcing it out is quadruple; but on reflection, he understands, that the water by running away more quickly from a pressure, is less affected by it. Because a body shot upward with a double velocity gains a quadruple height, the jet issuing with only double velocity from four times the depth, still reaches the level of the surface of the reservoir.

The knowledge of this rule is of the greatest importance in the construction of water-works, because when joined with another rule which assigns the effect of friction in pipes, it ascertains the quantity of water which a conduit of a certain magnitude will deliver from any given distance and elevation.

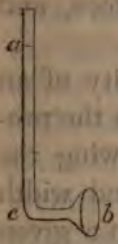
It is a curious fact, that more water issues from a vessel through a short pipe, than through a simple aperture of the same diameter with the pipe; and still more will come if the pipe be funnel-shaped, or wider towards its inner extremity. The reason is, that the issuing particles coming from all sides to escape, cross, and impede each other in rushing through a simple opening, as is proved by the narrow neck which the jet exhibits a little beyond it. But in a tube, this narrowing of the jet cannot happen without leaving a vacuum around the part, and the pressure of the atmosphere, resisting this, causes a quicker flow. The funnel-shape leads the water by a more gradual inclination to the point of exit, and still farther prevents the crossing among the particles.

The friction or resistance which fluids suffer in passing along pipes is much greater than might be expected. An inch tube of two hundred feet in length, discharges only one-fourth part of the water which would escape directly from the reservoir; and air passing along tubes, is so much retarded, that when gas-lights were first proposed, some engineers feared that this circumstance would be fatal to the enterprize.

Higher temperature in a liquid increases remarkably the quantity discharged by a pipe or orifice; because it diminishes that cohesion of the particles which is found in certain degrees in all liquids, and which affects so much their internal movements.

The progress of water in an open conduit, such as the channel of a river or aqueduct, is influenced by friction in the same manner. A river drawing its waters from an elevation of 1,000 feet above the level of the ocean, would pour them out, but for the resistances in the channel, with the velocity of water issuing from the bottom of a reservoir 1,000 feet deep; that is, at the rate of about 170 miles per hour. The ordinary flow of rivers is about three miles per hour, and their channels slope three or four inches per mile.

The velocity of a water current is easily ascertained by immersing in it the end *b* of such a tube as here represented, with its funnel-shaped mouth turned towards the stream. The water in the tube will stand above the surface of the stream, as at *a*, and the velocity of an issue from a reservoir corresponding to that height, as explained in page 403, will be the velocity of the current. A similar contrivance may be made to measure the velocity of the wind, by having the angle of the tube at *c* bent further down and filled with water.



The friction of water moving in water is so great, that a small stream directed through a pool, and rapid enough to rise over the opposite bank, will soon empty the pool. Extensive fens have been drained on this principle. The friction between air and water is also singularly strong, as is proved on a great scale in the magnitude of the ocean waves produced by it; and on a small scale in the amusing experiment of making a light round body dance or play upon the summit of a jet of water: a chief cause of its remaining there being, that the current of air rising around the jet by reason of the friction, presses it inwards again, whenever it inclines to fall over. A little oil thrown upon the surface of water soon spreads as a thin film all over it, and defends it from the farther contact of air. If this can be done at the windward side of a pond where the waves begin, the whole surface soon becomes as smooth as glass; and even out at sea, where of course the commencement of the waves cannot be reached, oil thrown upon them smooths their surface, and prevents their curling over or breaking.

A common mode of telling the velocity of an open stream, is to note with a stop-watch the progress of a body floating in it; and knowing the velocity of the water, and the depth and width of the channel, the quantity delivered in a given time, becomes a matter of simple calculation. The speed of the wind is found by measuring that of the shadow of a cloud passing across a field.

The flux of water through orifices under uniform circumstances is so steady, that before the invention of clocks and watches, it was employed as a means of dividing time. The vessels were called *clepsydræ*.

The most magnificent examples that ever existed, or probably ever will exist, of artificial watercourses, were the aqueducts of ancient Rome, about twenty in number. Several of them exceeded forty miles in length; they passed through mountains, and were borne on tiers of splendid arches across the vallies. They were constructed with such materials and so skillfully, that the chief of them are perfect to this day. Considered as one object, they rank, in point of grandeur, before any other work of human art, not excepting the pyramids of Egypt.

While the aqueducts are cited as specimens of grandeur, we may mention the fountains in the gardens of Italy and France, and particularly those at Versailles, as specimens of beauty. In these last the most magical effects are produced by varying the ways in which water is made to spout from orifices. In one place it is seen darting into the air as a straight upright pillar; in others many such pillars rise together, like giant stalks of corn; sometimes, from an inclination given to the jets, they bend so as to form beautiful arches, which appear the roofs of apartments built of water; or they mingle together with endless variety; here and there water-throwing wheels send out spiral streams, and hollow spheres with a thousand openings, are the centres of immense bushes or trees of silvery boughs. These effects, amidst cascades, smooth lakes, and scenes of lovely landscape, constitute a whole as enchanting, perhaps, as art by moulding nature has ever produced, or as fancy has ever conceived.

As relates to "*Waves*," their form, magnitude and velocity, admit of deep mathematical research; and the subject is rendered the more interesting, because certain phenomena of *sound* and *light* are of kindred nature. Here, however, it must be treated with all possible brevity.

A stone thrown into a smooth pond, causes a succession of circular waves to spread from the point where it falls, as a common centre. These diminish in elevation as they expand, and each new one is less raised than the preceding, so that gradually the liquid mirror is again as perfect as before. Several stones falling at the same time in different places, cause crossing circles, which however do not disturb the progress of each other. The phenomenon is seen in beautiful miniature at each leap of the little insects which cover the surface of our ponds in the calm hours of summer.—The rationale of the phenomenon is as follows. When the stone falls into the water, because the liquid is incompressible, a part of it is displaced laterally, and becomes an elevation or circular wave around the stone. This then falls downwards and outwards in obedience to the laws of fluidity, and the circle is seen to spread. In the mean time, where the stone descended, a hollow is left in the water, but owing to the surrounding pressures, is soon filled up, by a sudden rush from below; and the rising water does not stop at the exact level, but like a pendulum sweeping past the centre of its arc, rises as far above as the depression was deep. This central elevation now acts as the stone did originally, and causes a second wave, which pursues the first; and in subsiding, like the pendulum still, it falls again as much below the level as it had mounted above; hence it has to rise again, again to fall, and so on; sending forth a new wave at each alternation. Owing to the friction among the particles, each new wave is less raised than the preceding, and at last the appearance dies away.

So absolutely level is a liquid surface, and so sensitive, that the effect of any disturbing cause is perceived at great distances. A boat rowed across a still lake ruffles its surface to a great extent; and although the widening waves become at last so faint as not to be perceptible to the eye, they still produce a rippling noise where they fall among the pebbles on the shore. In seas liable to sudden but partial hurricanes, the roar of breakers on distant coasts often tells of the storm which does not otherwise reach them. The author once, in the eastern ocean, had an opportunity of contemplating waves of extraordinary magnitude rolling along during a gloomy calm, and therefore with unbroken surface, and appearing like billows of molten lead. It was afterwards ascertained that at that very time, about one hundred miles to the north-east, four of the finest ships of the India Company were perishing in a storm.—In the polar seas, which are comparatively tranquil, because defended from the wind by surrounding islands of ice, a few sudden waves are occasionally observed, and then all is calm again. Such a phenomenon announces that the occurrence described at page 286, has happened somewhere, of an island of ice turning over because the place of its centre of gravity is changed by partial melting.

A wave passing through a gap or opening, spreads from it as a new centre; and a wave coming against a perpendicular surface of wall or rock, is completely reflected from it, so as to have the appearance of coming from a point as far beyond the wall, as its real origin or centre was distant on the side where it is moving.

The common cause of waves is the friction of the wind upon the surface of the water. Little ridges or elevations first appear, which by continuance of the force gradually increase, until they become the rolling mountains seen where the winds sweep over a great extent of water. The heaving of the bay of Biscay, and still more that of the open ocean beyond the southern capes of America and Africa, is one extreme, and the stillness of the tropical seas which are guarded by near encircling lands is the other. In the vast archipelago of the east, where Borneo, and Java, and Sumatra lie, and the Molucca islands and the Phillipines, the sea is often fanned only by the land and sea breezes, and is like a smooth bed, on which these islands seem to sleep in bliss—islands in which the spice and perfume gardens of the world are embowered, and where the bird of paradise has its home, and the golden pheasant, and a hundred others of brilliant plumage; whose flight is among thickets so luxuriant, and scenery so picturesque, that European strangers find there the fairy land of their youthful dreams.

In rounding the Cape of Good Hope, waves are met with, or rather a swell, so vast, that a few ridges and a few depressions extend a mile. But these are not so dangerous to ships as a *shorter* sea, as it is termed, with more perpendicular waves.

The slope in the former is so gentle, that the rising and falling are scarcely felt; while the latter, by the sudden tossing of the vessel, is often destructive. When a ship is sailing before the wind, and riding over this *long swell*, she advances as if by leaps; for as each wave passes, she is first descending headlong on its front, acquiring a velocity so wild that she can scarcely be steered; and soon after, when the wave has glided under her, she is climbing on its back, and her motion is slackened almost to rest, before the following wave arrives.

The velocity of waves has relation to their magnitude. The large waves just spoken of, proceed at the rate of from thirty to forty miles an hour.—It is a vulgar belief, that the water itself advances with the speed of the wave, but in fact the *form* only advances, while the *substance*, except a little spray above, remains rising and falling in the same place, according to the laws of the pendulum. A wave of water, in this respect, is exactly imitated by the wave running along a stretched rope when one end is shaken; or by the mimic waves of our theatres, which are generally the undulations of long pieces of carpet, moved by attendants. But when a wave reaches a shallow bank or beach, the water becomes really progressive, because then as it cannot sink directly downwards, it falls over and forwards, seeking its level.

So awful is the spectacle of a storm at sea, that it is generally viewed through a medium which biases the judgment; and, lofty as waves really are, imagination makes them loftier still. No wave rises more than ten feet above the ordinary level, which, with the ten feet that its surface afterwards descends below this, gives twenty feet for the whole height, from the bottom of any water-valley to the summit. This proposition is easily proved by trying the height upon a ship's mast at which the horizon is always in sight over the top of the waves; allowance being made for accidental inclinations of the vessel, and for her sinking in the water to much below her water-line, at the instant when she reaches the bottom of the hollow between two waves. The spray of the sea, driven along by the violence of the wind, is of course much higher than the summit of the liquid wave; and a wave coming against an obstacle, may dash to almost any elevation above it. At the Eddystone light-house, when a surge reaches it which has been growing under a storm all the way across the Atlantic, it dashes even over the lantern at the summit.

It has been proposed to construct *submarine boats* or vessels to swim so deep in the water as to be below the superficial motion of the waves, and therefore beyond the influence of storms at the surface. Such a boat has been tried with considerable success; and the increasing familiarity with submarine matters since the invention of the diving-bell may ultimately lead to great improvements, and render the submarine vessel so commodious and safe, that persons who dislike the sickening motion of the surface may prefer sailing underneath.

The magnitude of waves is well judged of when they are seen breaking on an extended shore or beach. In the deep sea the wave is only an elevation of the water, sloping on either side; but as it rolls towards the shore it becomes more perpendicular in front, and at last curls over and falls with its whole weight, and with a noise, when several miles of it break at the same instant, which shakes the country round.

On the east, or Coromandel coast of India, at certain seasons, vast waves are constantly breaking; and as there are no good harbours there, communication between the sea and land is impossible by ordinary boats. The natives of the coast, at Madras for instance, are almost amphibious. They reach ships beyond the breakers by the help of what are called *catamarans*, consisting of three small logs of wood tied together: on this they secure themselves, and boldly advance up to the coming wall of water, which they then shoot into, and rise to the smooth surface beyond it, like water-fowls after diving.—Boats unsuited to the breakers often perish in them. The author had gone on shore with a watering party on the coast of Sumatra, and during the hours that were spent there, a swell had arisen in the sea, which now appeared on the shore as lofty breakers. The cutter in which he was regained the ship in safety, but a larger boat which followed was overwhelmed, and an officer and part of the crew perished.

There is a phenomenon observed at the mouths of many great rivers, called the *Boar*, which has some resemblance to a wave. When the tide returning from the sea meets the outward current of the river, and both have the force which in certain situations belong to them, the stronger mass from the ocean assumes the form of an almost perpendicular wall, moving inland with resistless sweep: this is called the boar. In the different branches of the Ganges it is seen in a remarkable degree. Smaller boats and skiffs cannot live where it comes; and as it passes the city of Calcutta, even the large ships at anchor there are thrown into great commotion, and sometimes their cables give way.

The nature and effects of this boar are closely imitated upon those coasts where extensive tracts of sand are left uncovered at low water. In such situations, of which there are many on the western shores of Britain, the returning tide is seen advancing with steep front, and with such rapidity, that the speed of a galloping horse can scarcely save a person who has incautiously approached too near. Many, every year, are the victims of temerity or ignorance on these treacherous plains.

"*Fluids resisting the motion of bodies immersed in them, or themselves moving against other bodies.*" (*See the analysis, page* 402.)

The same force is required to give, or to take away, or to bend motion, in a fluid, as in an equal quantity of solid matter. A pound of water enclosed in a bladder, is not more easily thrown to a given height than a pound of ice, or of lead; nor, if falling into the scale of a weighing-beam, does it require less as a counterpoise; nor if made to revolve at the end of a cord, as the ice or a stone might revolve in a sling, does it render the cord less tight.

Many persons looking carelessly at this subject, would expect, that if a body moving through a fluid at a given rate meets a given resistance, it should just meet double resistance when moving with double speed. Now four times the power is required to produce a double rate.

This fact, when more closely examined, is easily understood. A boat which moves one mile per hour, displaces a certain quantity of water, and with a certain velocity;—if it move twice as fast, it of course displaces twice as much water, and requires to be moved by twice the force on that account; but it also displaces every particle with a double velocity, and requires another doubling of the power on this account: the power then being doubled on two accounts, becomes a power of four. In the same manner with a speed of three, three times as many particles are moved, and each particle with three times the velocity; therefore a force of nine is wanted to produce it: and so for a speed of four, a power of sixteen is wanted; and for a speed of five, a power of twenty-five. The corresponding numbers, up to a speed of ten, are shewn in the following table.

Speed	1	2	3	4	5	6	7	8	9	10
Corresponding resistance	1	4	9	16	25	36	49	64	81	100

So that the force of one hundred horses would only drag a boat ten times as fast as the force of one horse. Arithmeticians express the relation shewn in this table, by saying *that the power required to move a body in a fluid, increases as the square of the speed.*

There is not a more important truth in physics than this; it explains so many common facts, and becomes a guide on so many occasions.

It shews at what a heavy expense of coal high velocities are obtained in steam-boats. If an engine of 49 or 50 horse power would drive a boat 7 miles an hour, two engines of 50, or one of 100 would be required to drive it 10 miles, and three such would only drive it 12 miles.—For the same reason, if all the coal which a ship could conveniently carry were just sufficient to drive her 1,000 miles, at the rate of 12 miles per hour; it would drive her 3,000 at the rate of 7 miles per hour; and nearly 6,000 at a rate of 5 miles per hour. This is a very important consideration for persons concerned in steam navigation to distant parts.

The same law shews the folly of putting very large sails on a ship: the trifling advantage in point of speed by no means compensates for the additional expense of making and working the sails, and the risk of accidents in bad weather. The ships of the prudent Chinese have not one-third so much sail for the same tonnage as those of Europe, and yet they move but a little slower. A ship under jury-masts does not lose so much of her usual speed as most people would expect.

This law explains also why a ship glides through the water one or two miles an hour when there is hardly any wind, although with a strong breeze she would only sail at the rate of eight or ten miles. The 100th part of that force of wind which drives her ten miles an hour will drive her one mile per hour, and the 400th part will drive her half a mile. Thus also a few men in a boat can pull a large ship in a calm at a sensible rate.

These considerations shew strikingly of what importance to navigation it might be to have, as a part of a ship's ordinary equipment, one or two water-wheels, to be affixed upon the ship's side when required, like the paddle-wheels of a steamboat, and by turning which the crew might easily deliver themselves from the tedium, and often more disastrous consequences of a long calm at sea.—The author was in a ship completely becalmed for weeks on the Line; during which most wearisome period, the breezes were often seen roughening the water a mile or two farther on, and any means that could have enabled the ship's company to drive her a little distance might have saved the delay. The wheels might be driven by connexion with the capstan, which the crew would most willingly turn to escape from their wearisome inactivity. Delay in a large vessel with troops on board often costs hundreds of pounds per day, and may retard the execution of important projects.—But the propelling of the ship in a calm seemed to the author to be the least important purpose which such wheels might serve. If from disease, fatigue, or otherwise, the crew were inadequate to existing necessities, two wheels affixed to the extremities of an axis running across the ship, as in a steam-boat, might be equivalent in many cases to additional hands, or to a steam-engine of great power. Acted upon by the water as the ship sailed, they would turn with the force of water-wheels on shore, and might be made to move the pumps, to hoist the sails, and to do any work which a steam-engine could perform. Many a gallant vessel has perished because the exhausted crew could no longer labour at the pumps, and where such water-wheels or a windmill-wheel would have performed the duty most perfectly.

The law that resistance to a body moving in a fluid increases in a greater proportion than the speed of the body, applies where the fluid is aeriform, as well as where it is liquid.

A bullet shot through the air with a double velocity, experiences four times as much resistance as with a single velocity: and it is farther true, that when the velocities of bodies moving in air are very great, the resistance increases in a still quicker ratio than in liquids: probably because the compressibility of air allows it to be very much condensed or heaped up before the quick moving body. It is useless to discharge a cannon ball with a velocity exceeding 1,200 feet in a second, because the powerful resistance of the air to any velocity beyond that, soon reduces it to that at least.

The rule of mutual action between a solid and fluid, now explained, holds equally when the fluid is in motion against the solid, as when the solid moves through the fluid.

If a ship be anchored in a tide's way where the current is four miles an hour, the strain on her cable is only one-fourth part as great as if the current were eight miles.

A wind moving three miles an hour is scarcely felt; if moving six miles, it is a pleasant breeze; if twenty or thirty miles, it is a brisk gale; if sixty, it is a storm; and beyond eighty, it is a frightful hurricane, tearing up trees and destroying every thing.

Supposing the wind to move one hundred miles per hour, there are one hundred times as many particles of matter striking any body exposed to it, as when it moves only one mile per hour, and each particle strikes moreover with one hundred times the velocity or force: therefore the whole increase of force is a hundred times a hundred, or ten thousand. This explains how the soft invisible air may by motion acquire force sufficient to unroof houses; to level oaks which have been stretching their strong roots around for a century; and in some West-India hurricanes, absolutely to brush every projecting thing from the surface of the earth.

This law of rapidly increasing resistance assigns a limit to many velocities, both natural and artificial.

It limits the velocity of bodies falling through the air. By the law of gravity, a body would fall with a constantly accelerating speed, but as the resistance of the air increases still more quickly than the falling velocity, the two opposing influences at a certain point balance, and the motion becomes uniform.

The *parachute*, by means of which a person may descend to the earth with safety from a balloon at any elevation, is a thing resembling a large flat umbrella. The aeronaut attaches himself underneath it, and when it is let loose from the balloon, he is supported by the resistance which its broad expanse experiences in falling through the air. It descends with a uniform motion after the first second or two, and its breadth is generally such, as to allow a velocity of about eleven feet in a second, or that which a man acquires in jumping from a chair two feet high.

No ship can sail faster than fifteen miles in an hour.

No fish can swim with a velocity exceeding twenty miles an hour; not the dolphin, when shooting ahead of our swiftest frigates, or the salmon, when darting forward with speed sufficient to ascend a water-fall of many feet.

And the flight of birds through the thin air has a limited celerity. The crow, when flying homewards against the storm, cannot face the wind in the open sky, but skims along the surface of the earth in the deep vallies, and wherever the swiftness of the wind is retarded by terrestial obstructions. The great albatross can stem upon the wing the current of a gale, keeping company with a driving ship where the air is passing at the rate of a hundred miles an hour, but perhaps this is the limit to which winged speed, and therefore, living speed, may reach. The bird called the *Stormy Petrel* lives chiefly in the midst of the Atlantic Ocean, but the irresistible violence of the wind occasionally sweeps it from the waves, and causes its appearance on the western shores of Europe. Vessels from the high sea, approaching a coast from which the wind blows, generally become resting-places to exhausted land birds, that have been driven off the shore by wind which they had not strength of wing to stem;—sad evidences of the myriads which are constantly perishing where no resting-place is found, and where no human eye notes their fate.

The action or resistance of a meeting fluid and solid, is influenced by the shape of the solid.

If a flat surface experience a certain resistance in moving through a fluid, a projecting surface like that of a sphere or short wedge is resisted in a less degree, and a concave surface in a greater.

The following are instances of projecting surface. Fishes are wedge-like both before and behind;—Birds are so also, and they stretch out their necks while flying so as to be like sharp points, dividing the air. In the form of the under part of boats and ships, men have imitated the shape of fishes. The light wherries which shoot about upon the surface of the Thames, seem the very essence of what the imagination can picture of form to combine utility and grace. There are boats used in China, called *snake boats*, which are only a foot or two broad, but perhaps a hundred feet in length: when moved, as they often are, by nearly a hundred rowers, their swiftness is extreme. The problem which is to assign for a ship's hull or bottom, the best possible form that she may have speed of sailing, is not yet completely solved; so that a kind of empiricism still prevails in the matter: yet in war time, when vessels have to chase and to flee, speed becomes of the greatest importance. The sailor's heart swells with delight when he finds his well-beloved vessel outstripping competitors, both because of the many immediate advantages, and the glory of superiority.

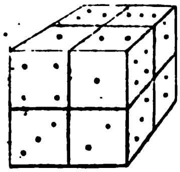
The following instances exhibit the mutual influence of meeting solids and fluids, where the surface of the solid is plane or concave.

In a water-wheel, whether the water be moving against the wheel, as is the case where a stream acts to drive machinery, or the wheel be moving against the still water, as in the case of the paddle-wheels of a steam-boat, the extended faces of the vanes or float-boards give or receive a powerful impulse. When a wheel with float-boards merely dips with its lower part into a stream of water, and is driven by the momentum, it is called an *undershot-wheel;* when the water reaches the wheel near the middle of its height, and turns it by falling on the float-boards of one side as they sweep downwards in a curved trough fitting them, the modification is called a *breast-wheel;* and when the float-boards are shut in by flat sides, so that they become the bottoms of a circle of cavities or buckets surrounding the wheel, into which the water is allowed to fall at the top of the wheel, and to act by its weight instead of its momentum, the modification is called the *overshot-wheel.* To have a maximum of effect from these different kinds of wheels, they are generally made to turn with a velocity of about a third of that of the water. The subject of water-wheels is of much importance in practical mechanics, for moving water performs a great deal of labour for man.

Oars for boats are made flat, and often a little concave, that the action between them and water may be great. The web-feet of water-fowl, in advancing, collapse like a shutting umbrella, but open outwards in the thrust backwards, so as to offer a broad flat concave surface to the water. The expanded wings of birds are a little concave on the under side. The sails of ships are allowed to swell and become hollow to receive a fair wind.

The resistance between a solid and fluid is nearly proportioned to the extent of the surface of the solid; hence large bodies are less resisted in proportion to their weight than small ones, because they contain more matter in proportion to their surface.

A bullet, or any solid of two inches diameter, has eight times as much matter in it as a similar solid of one inch, while it has only four times the surface. Thus eight dice or little cubes put together, form a larger cube, of which the surface is only four times as great, and the edge only twice as long as of the single die; and twenty-seven dice together just form a cube with sides three times as long, and surface nine time as great. All solids similar to each other, have this kind of relation, which, in the language of the science of quantity, is called the relation of cubes; or they are said to be to each other as the cubes of any of their corresponding lines. Hence, if a bullet of eight pounds and a bullet of one pound be shot off with equal velocity, that of eight pounds will go much the farther, because it has only four times the surface of the one-pound bullet, but eight times its weight, and therefore eight times its motal inertia or force.



This important rule explains why shells and large shot may be thrown four or five miles, while there is a regular diminution of range, as the size of the projectile is less, through the series of smaller cannon balls, musket bullets, pistol and swan-shot, and the common small-shot of the sportsman, all of which are discharged from their respective pieces with the same commencing velocity. Water thrown from a gun or powerful syringe is sometimes used to stun birds without hurting their plumage; but it soon divides in the air so minutely that it only reaches to a short distance.

Water falling through the air from a great height, goes on suffering a division into smaller and still smaller portions, until at last they may be said to be nearly all surface, and then the resistance of the air lets them fall very slowly indeed. The relation of the size and resistance is well shewn by the different celerity in the descent of a minute fog, a drizzling mist, and common rain. The toy called the *water-hammer*, is merely a little water enclosed in an exhausted or perfectly empty tube. When the water is made to fall from one end of this to the other, as there is no air to impede or divide it in its descent, it falls as one mass, and makes a sharp noise like the blow of a hammer.

This law explains why a spider's thread or a single filament of silk floats so long in the air before it falls;—why there is almost constantly suspended in the air wherever active man resides, that immense quantity of very minute solid particles, which, when rendered visible by the sun's light passing directly through them, are called motes in the sunbeam—particles which are constantly settling on household furniture, and which have daily to be removed in cleaning;—why the fine dust sent aloft during the eruption of volcanoes is often carried by the wind to a distance of many hundreds of miles;—why in the deserts of Africa the strong winds often transport fine sand from place to place, overwhelming caravans, and forming new mountains, which succeeding blasts are again to lift;—why in the bottom of a river, or in a tides-way, fine mud is found where the current is very slow; sand where it is quicker; and pebbles, or large stones, where it is quicker still; while in rapids and waterfalls, only solid rocks, firmly planted in the earth, can resist the fluid force.

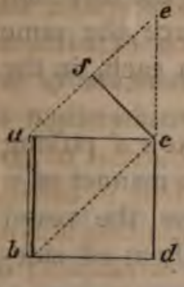
This law explains the operation of *levigating*, which obtains substances insoluble in water in the state of a very fine powder. The substance is first ground or powdered in any ordinary way, and mixed with water. All the grosser parts soon fall to the bottom, while the fine dust remains longer suspended. This is then obtained separately, by pouring the liquid which bears it, into another vessel, and allowing time for the slow subsidence. The fine powder of flint used in the manufacture of porcelain is obtained in this way; as is, also the powder of calamine stone and other powders used in medicine and the various arts.

This law further explains how, by means of air or water, bodies of different specific gravities, although mixed ever so intimately, may be quickly and mechanically separated. If pieces of cork and lead be allowed to fall through the air together, the lead will reach the ground first, and may then be swept away separately before the cork arrives: in a vacuum the whole would fall together, as proved by the common experiment of the guinea and feather in the receiver of an air pump. When a mixture of corn and chaff is showered down from a sieve in a current of air, the chaff from being longer in falling is carried far by the wind, while the heavier corn falls almost directly down: thus the farmer, by winnowing in either a natural or artificial current of air, separates his grain from the chaff; and if he desire it, he may divide the grain itself into portions of different quality. Similar to the operation of separating chaff from corn by wind, is that of separating sand and mud from gold-dust by water. The soil containing gold-dust is spread on a flat surface, over which a current of water is made to pass. This carries away the lighter rubbish and leaves the gold. If a mass of metal be affixed on the end of a rod of wood, the rod, whether simply falling through the air, or advancing in it as an arrow, will follow the heavy metal as a point. The cork of a shuttlecock is always foremost for the same reason.

The instances enumerated under this head serve to shew how many and varied the results may be which flow from one single principle.

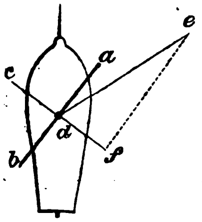
When a fluid and a solid meet each other, the shock or effect is always perpendicular to the surface of the solid, whatever be the obliquity of their approach, but is less as this obliquity is greater.

Suppose *a b* to be a board or flat surface, seen edgeways, any fluid approaching it, in whatever direction, must act upon it, as if approaching perpendicularly from *c d*, because supposing the surface to be smooth, the fluid can take no hold of it to push it endways, either towards *a* or *b*.—But the impulse of a stream acting



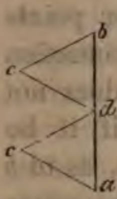
on the surface will be less if it be oblique, both because less fluid will touch and because the velocity of the approach will be less. The line *c d* marks the breadth of the part of a direct stream which reaches the board, and the shorter line *f c* the breadth of a stream coming obliquely in the direction *c b:* and in the oblique stream, if the line *c b* mark the whole velocity, and therefore the whole force, the shorter line *c a* will mark the velocity with which it approaches the board, and therefore will shew the loss of force from the obliquity of action.

Hence the wind blowing upon the sail of a ship, always presses it directly forward, or perpendicularly to its surface, whatever the obliquity of the approach; but it acts less forcibly as the obliquity is greater. If the wind be represented, as to direction and strength, by the line *e d* approaching the sail *a b*, it will act on the sail as if it came from *f* to *d*, or as if the sail were pulled by a rope *d c*. We see in this how a ship can be made to sail against the wind in a certain degree; for all the sails being *trimmed*, as it is called, or fixed so as to receive the wind in the direction here shewn, they all act to produce the same result as if ropes were pulling from each, in the direction *d c*.



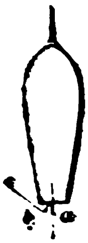
The reason again why a rope like *c d* pulling sideways as well as forwards, in the manner of a tow-rope from a canal boat, makes the vessel advance rapidly forward, but scarcely at all sideways, is, that she is formed to pass forward perhaps twenty times more easily with her sharp bow, than sideways with her long flat keel; and therefore a force that were pulling just as much sideways as forwards, would make her advance twenty miles in the direction of her keel, that is forwards, for one mile which she would deviate sideways.—The deviation sideways which takes place to a certain extent whenever the wind is at all oblique, is called the *lee-way*.

A vessel having to sail from *a* to *b*, directly against the wind, is obliged to sail close to the wind, as explained in the last paragraphs; first perhaps to *c*, with the right or starboard side to the wind, then to *tack*, as it is called, or turn round, at *c*, and to sail to *d*, with the left or larboard side to the wind; then to go on the starboard tack to *e*, and from thence to the port at *b*.



In making way against a *contrary wind*, the sails of a ship, as shewn in the last page, are pointed so nearly edgeways to the wind, that unless they are very flat, a great portion of their surface becomes useless. The Chinese manner of rigging is, in this respect at least, superior to the European; for owing to bamboo reeds attached across the sails, they are rendered as flat as boards. If they point edgeways to a spectator, he only sees the masts which support them.

The law now under consideration explains the action of the *rudder* of ships,—that contrivance, by which a single steersman can direct the course of a mighty vessel through rocks and shoals, more steadily and safely, than the most adroit driver on shore can guide his steeds. The helm or rudder is a projection from the stern of the ship, attached to what is called the stern-post, by strong hinges, in the manner of a door or gate, and moved by a beam or lever called the *tiller*, proceeding forwards to where the steersman stands. In small vessels the tiller is above the deck, and the steersman applies his hand directly to it; but in larger ones it is below, and is moved by ropes, rising from it to *the wheel* on the deck, where the helmsman stands with the compass before him. While the rudder points directly astern, as to *a*, like a continuation of the keel and stern-post, it does not affect the vessel's course; but if it be inclined ever so little to one side, as to *b* on the left or *larboard* side, the water immediately acts there in the direction *c b*, perpendicular to the surface of the rudder, and pushes the stern to the right or starboard side, which action is equivalent to pulling the bow to the larboard.



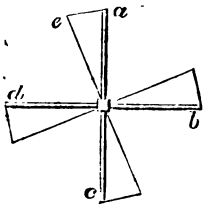
It is possible to make a ship or boat steer itself, by placing a powerful vane on the mast-head, which shall pull the tiller-ropes by two projecting arms as it turns with the wind. If it were desired to make the ship sail directly before the wind, the tiller-ropes would be fixed to the vane so that the helm should be in the middle position, when the vane were pointing directly forward; and were the vessel then from any cause to deviate from her course, the vane by its changed position with respect to her, would have produced a corresponding change on the position of the helm, just such as to bring her back to the true course. It is evident that, by adjusting such a vane and rudder to each other, any desired course might be obtained, and which would remain the same while the wind changed not. The vane would require to be of large size to have the necessary power—a wide hoop, for instance, with canvass stretched upon it; and the rudder, that it might turn easily, would be hung by an axis through its middle, instead of, as usual, by hinges at one edge. Cases have occurred where persons after shipwreck might have sent intelligence of their disaster to a distant coast, by a small vessel, or even a block of wood fitted up in this way; and the method might frequently save an additional hand in a boat's crew. It admits also of other applications.

As fluids act on surfaces, perpendicularly to them, the water on the right side of a ship's bow presses towards the left side; but as there is just an equivalent and contrary pressure there, the ship holds her course evenly between the two, or straight-forwards. When a ship, however, lies over or *heels*, owing to a side wind, that side of the bow which sinks most in the water is more pushed than the other; and were it not for a counteracting inclination of the rudder then made, constituting what is called *weather helm*, the ship's head would come round to the wind. Now ships so rarely have the wind exactly a-stern, that to diminish the almost constant necessity of *weather helm*, the masts, and consequently the mass of the sails, are placed more towards the bow than the stern.

Because the bow of a ship is oblique downwards as well as sidewards, the water, when she moves, is constantly tending to lift the bow; hence when a vessel is dragged by a low horizontal rope, or is moved by paddle-wheels, the bow rises much out of the water, and the stern sinks in the hollow or furrow of her track: but when she is driven by sails, as these are high on the mast, and are acting therefore by a long lever to depress the bow, the two opposing tendencies just balance each other, and the vessel sails evenly along.

The form of the fore part of a ship has less influence upon her speed of sailing, than the form of her hind part or *run*. When a ship is at rest, there is of course as much forward pressure of the water about the stern as of backward pressure on the bow; but when she sails, she is running away from the pressure behind, and increasing that in front. A gradual tapering of the hind part therefore, or a *fine-run*, as it is called, which allows the water to apply itself readily to it, as it passes along, must quicken much the rate of sailing. A tree or tapering mast of a ship can be drawn through the water the most easily with the large end foremost.

The *common windmill* furnishes another illustration of the action of fluids on oblique surfaces. The face of the windmill is turned directly to the wind, but the four flat vanes or sails of which the great wheel consists are individually oblique. Thus the edge *a* of



the vane *a e*, is more forward as regards the coming wind or a spectator in front, than the edge *e*, and the action of the wind therefore, being perpendicular to the oblique surface *a e*, pushes it in the direction *a*. The same remark applies to each of the other vanes where the edges *b*, *c* and *d* are in front, while those marked by the fainter lines are behind. The law of the "decomposition of forces," explained at page 80, tells in what proportions the force of the wind is exerted to push the wheel backwards against its supports, and to turn it round.

Windmills were first used in Europe in the fourteenth century. They are still of great importance in countries where there are no waterfalls and little fuel for steam engines. In some of the richest European landscapes, every height has its busy windmill, grinding corn, or sawing wood, or pressing oil-seeds; and in the low plains, they pump water, or incessantly drain the land.

The smoke-jack of our chimnies is a small windmill, driven by the ascending current of air in the chimney.

The feathering of an arrow acts in part on the principle of the windmill. The feathery projection from the shaft is not quite straight, but winds round it a little, like the thread of a screw; and therefore, the arrow constantly turns as it flies, and goes straight to its object although the shaft itself be bent, because any deviation is constantly correcting itself.

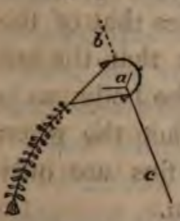
It might be supposed that a wheel which the wind turned by *direct* action on the rim, as water turns common water-wheels, would be preferable to the common windmill-wheel turned by *oblique* action on the face; and accordingly, a wheel like a water-wheel, only with broader vanes, has been placed in a house or cover, so that only one side was exposed to the wind; but it is a powerless machine. Although the oblique vaned wheel applies to use only half perhaps of the force of the air which reaches it, still its wide expanse receives a stream of air generally of thirty feet in diameter, while a small window would admit enough for a wheel of the other construction.

There are situations, on the other hand, where it would be an advantage to make water-wheels like the common windmill-wheel, *viz.* where the stream has slow motion, and is deep enough to allow the whole wheel to be immersed.

A small wheel of this kind with broader vanes has been used as a means of ascertaining the rate of a ship's sailing, by allowing it to drag a-stern, and noting the number of revolutions made in a given time. It may be called a *water-screw.*

A windmill-wheel made to turn during a calm by some force applied to its axle, would be pressed endways or in the direction of its axle, with a certain proportion of the force used, just as if the wind were blowing upon it,—owing to the re-action of the still air, through which its oblique vanes were made to sweep. Such a form of wheel fitted to work in water has been applied at the bow or stern of steam-boats, to propel them in canals where there was no room for side wheels. But as from the obliquity of the surfaces, only part of the power is used to propel, while the remainder is wasted in the lateral strain or twisting of the water, the method is not applicable to general purposes.

Two small windmill-wheels placed horizontally one above the other, and made to turn in opposite ways by a spring or otherwise, would rise in the air, carrying a certain load with them, and would constitute, therefore, a flying machine.



A *paper kite* rises in the air for the same reason that a windmill vane turns. The cord is attached to it so as to make it present an oblique surface to the wind; and the wind acting perpendicularly to its surface, it rises as if pushed up in the direction *c a*, or drawn up in the direction *a b*. A kite might be made large enough to lift a man. Cats have been sent up at kites' tails, and have fallen down safely under parachutes from the greatest elevations: and perhaps it would be safer for a man to rise at a kite's tail to reconnoitre an enemy's position, than under a balloon, as was practised by the French during the revolutionary wars. The man under the kite might have the security of a parachute, and possessing the power of regulating the obliquity of attachment of the rope, could command his ascent or descent at pleasure.

The effect of using a single oar from the stern of a boat or vessel, to propel it in the manner called *sculling*, is referable to the law now under consideration. The oar or scull is made to vibrate from side to side, and in all its positions it has its pressing surface turned obliquely backwards; hence the re-action of the water propels the boat.—In China large vessels are moved by a single sculling oar, resting on a round-headed prop or nail at the stern, and half the ship's company may be urging it at the same time. A sculling oar may be regarded as a single vane of such a propelling wheel as above described, made to sweep across, behind the vessel, alternately to the right and to the left.

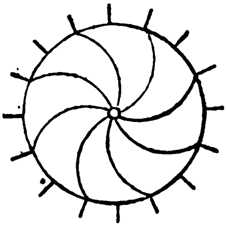
The action of a fish's tail, and of the bending of an eel or snake in water, resembles that of the sculling oar. Many people believe that the tail of the fish is only the rudder of the body, as is true of a bird's tail; but it is in fact the great instrument of motion, while the fins are only used to steady and direct the motion.

"*Fluids lifted in opposition to gravity.*" (*See the analysis, page* 402.)

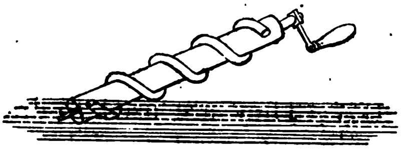
Water, as we have seen in former parts of this work, is to the living universe, what the blood is to the animal body, and a constant supply and circulation are required. This has been provided for to an extraordinary extent, by the operation of natural causes; but for many purposes of society, water is still required where there is no natural supply. A great variety of means have been employed for raising it, some of which, sufficient to illustrate the whole, are now to be considered.

A bucket attached to a rope may be pulled up by the hand, or the rope may be wound round a barrel or axle by means of a winch—or there may be a succession of buckets on a rope, rising one after the other, and descending again when emptied, on the opposite side of the wheel which lifts them: the rope to which they are attached being a circle or *endless rope*, and constituting with them what is called the *bucket machine*. Instead of buckets, on such an endless rope or chain there may be a succession of flat pieces of wood, which, on being drawn up through a large tube or barrel, like loose-fitting pistons, will raise a copious stream of water: this construction is called the chain-pump.—Or simply an endless rope, made of hair, and very rough, may be whirled quickly round two wheels above and below, and a mass of water adhering by friction to its rising half, will be thrown into a reservoir at the top where it passes over the upper wheel. Several such ropes may be joined side by side to increase the effect. But the most important of all water-raising engines are the *lifting and forcing pumps*, already described at page 317. They are used to draw from wells, to drain mines, to send a supply over cities from low sources, to pump ships, to throw water from fire-engines, and for other purposes.

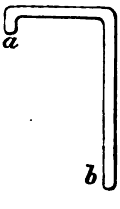
A stream of water may pass through a garden, or in the midst of fields, but will give beauty only without utility, unless it can be employed to irrigate the vegetable creation around. In the fields and gardens of Persia, where the heat of the sun is very intense, the streams are ingeniously made to lift a part of their water into reservoirs, from which it again flows in sloping channels to wherever it is required. A large water-wheel is placed so that the stream turns it, and on its circumference buckets are attached, which are filled as they sweep along below, and emptied into the reservoir as they pass above—or without buckets, the spokes or radii of the wheels are made hollow, and curved as here represented, so that when their extremities dip into the water at each revolution, they receive a quantity of it, which runs along them as they rise, and is discharged into a reservoir at the centre. These are called the *Persian wheels*, but they are in common use on the banks of the Nile, and elsewhere.



A pipe wound upon a barrel like a screw, and its lower mouth made to dip into water at each revolution of the sloping barrel, will also raise water; the lower halves of the turning pipe will always be full of it, and it will be rising in them to the top, as on an inclined plane. Archimedes was the inventor of this beautiful water-screw, and has left his name to it. It may be turned by hand, or by a passing stream which acts on the vanes of a water-wheel affixed to it.

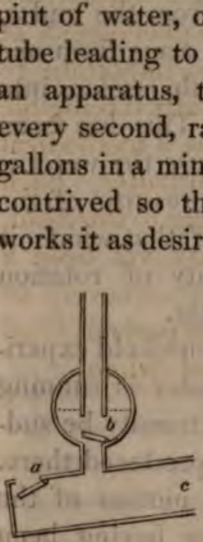


Water may be raised by producing centrifugal force at the upper end of a pipe containing it. Supposing the pipe to be bent as here represented, and the horizontal arm *a* to be turning like the spoke of a wheel, while the upright portion is kept steady like an axis, if the



pipe be once filled with water, it will continue to throw out a constant stream from the end *a.* There may be several horizontal arms from one larger upright pipe, all emptying themselves into a circular trough or reservoir. This has been called the *centrifugal pump,* because the water is raised in *b* as in a pump, by the pressure of the atmosphere, to supply the place of that which is thrown out from *a.* The velocity of rotation must bear proportion to the height.

It had long been observed, in household experience and elsewhere, that while water is running through a pipe, if a cock at the extremity be suddenly shut, a shock and noise are produced there. The reason is, that the forward motion of the whole water contained in the pipe having been instantly arrested, and the momentum of a liquid being as great as of a solid, the water strikes the cock with the same force as a solid lance of the same weight and moving with the same velocity. A leaden pipe, if of great length, is often widened or burst in this experiment.—Lately this forward pressure of an arrested stream has been used as a force for raising water, and the simple arrangement of parts contrived to render it available has been called the *water-ram.* It may be described as a sloping pipe in which the stream runs, having a valve at its lower end, to shut at intervals, and a small tube rising from near the end to a reservoir above, to receive a portion of the water at each shutting of the valve. Now in a channel ten yards long, two inches wide, and sloping six feet, water allowed to run for one second acquires momentum or force enough to drive about half a pint of water, on the shutting of the cock, into a tube leading to a reservoir forty feet high. Such an apparatus, therefore, with the valve shutting every second, raises about sixty half pints or four gallons in a minute. The valve is now ingeniously contrived so that the action of the stream itself works it as desired. Suppose this figure to represent the lower end of the water-ram, *a* is the opening by which the stream escapes from it, and the valve or flap seen below the opening is made so heavy, that the stream must run for a certain time to acquire force enough to shut it: in the instant when it does so, a little of the advancing water passes upwards through the valve *b* towards the reservoir: the water in the main pipe having then become stagnant again, has no longer power to keep the valve shut, which, therefore, falls open and the stream begins again, again to be arrested; and thus as long as the supply lasts, the action of the apparatus continues. Its action may be compared to the beating of an animal's pulse. The upright tube is made wider at the bottom where it first receives the water, so as to constitute there an air-vessel *b*, as described at page 296, which by the air's elasticity converts the interrupted jets first received into a uniform current towards the reservoir. The supply of air to this vessel is maintained by the contrivance called a *snifting valve*.



In these pages on the doctrines of fluidity, we have had to touch on many of the phenomena of nature and art which are the most important to man; yet we have seen how beautifully intelligible the whole become when referred by a methodical arrangement to the few fundamental truths. Each one of the many particulars belonging to this head, which now appear so obvious, has yet been a distinct step in the slow progress of discovery or invention, which when first made has perhaps filled some ingenious mind with the purest delight.

CHAPTER III.

SECTION IV.—ACOUSTICS, OR PHENOMENA OF SOUND AND HEARING.

ANALYSIS OF THE SECTION.

1. Sound *is heard when a sudden shock or impulse is given to the air or to any other body which is in contact directly or indirectly with the ear.*
2. *If such impulses be repeated at very short intervals the ear cannot attend to them individually, but hears them as a* CONTINUED SOUND, *which is* GRAVE *or* SHARP, *according as the impulses are few or many in a given time.*
3. *When the number of impulses producing some continued sound has a simple relation, as of half, third, fourth, &c. to the number producing some other sound which is heard either simultaneously or a little before or after, the ear is generally much and pleasingly affected by the circumstance; and such sounds are said to have* MUSICAL RELATION *to each other, or to be* CONCORDS, *while all others are termed* DISCORDS.
4. *The trembling which causes the sensation of sound* SPREADS *or is propagated in all bodies somewhat as a wave is in water, with decreasing strength as the distance increases, but with a velocity nearly uniform, and which in air is* 1,142 *feet per second.*
5. *Sound is* REFLECTED *from smooth surfaces, and hence arise many curious and pleasing effects, called* ECHOS, *&c.*
6. *The structure of the ear illustrates the laws of sound.*

Early inquirers into nature had remarked that in every instance of noise or sound there was present a shock or trembling of the sounding body, which was often visible, but sometimes only sensible to the touch, or discoverable by other effects. It was noted in the string of a harp; the reed of a hautboy; the prongs of a tuning fork; the lip of a bell. But it was reserved for the moderns to understand fully, that the animal organ called the ear, is merely a structure of parts admirably adapted to be affected by the concussions or tremblings of things around, and that sounds in all their varieties are merely such motions, affecting the ear through the medium of the air which surrounds us, or of some other body or bodies which connect the trembling thing with the head in which the ear is situated.

The delicacy and complicacy of an organ destined to feel and to distinguish such slight and varying influences, and the unspeakable importance of it to man as the means by which he receives and communicates thought,—besides its being the ever-watchful guard which warns him of surrounding occurrences; the channel by which the fascination of music enters, &c.,—render this subject, to those who love to read in nature the attributes of its author, a most favourite study.

Because all the bodies around us are immersed, in common with ourselves, in the ocean of air which covers the earth, we are much more frequently warned of the shocks and tremblings which we have been describing, by their effect on the air, than in any other way; and hence the early prejudice that air was necessary to sound, and hence the reason why the doctrines of sound have often been accounted a part of pneumatics. We shall now find, however, that all bodies convey these tremblings, and that air in many cases is neither the quickest nor the best carrier. Although our notions on the subject are thus corrected, it is still convenient to consider the doctrines of sound in this place.

1. "*Sound is heard when any sudden shock or impulse occurs in a body having communication by the air or otherwise with the ear.*" (*Read the analysis, page* 442.)

Common instances of a single impulse are—the blow of a hammer—the clap of hands—the crack of a whip—a pistol shot—any explosion—the thunder-clap.

The loudness of sound conveyed by air depends on the air's density. A bell enclosed in the receiver of an air-pump is heard less and less distinctly as the air is exhausted, and in a vacuum is not heard at all.—The blow of a hammer in a vacuum is not heard, if care be taken to prevent the shock from being communicated through neighbouring solid bodies.—In the thin air surrounding a lofty mountain-top the report of a pistol is much less loud, and human voices are weaker.—In the condensed atmosphere of a diving-bell a whisper is loud.—When volcanoes and various resemblances to the constitution of our earth were first discovered in the moon, some persons fancied that we should hear the thunder there:—but supposing it to happen, and to be ever so loud, it could not be heard on earth, because there is no medium to bear thither the pulses of sound—there is a vacuum between.

2. "*Impulses quickly repeated cannot be individually attended to by the ear, and hence they appear like a continued sound, of which the tone depends on the number of beats in a given time.*" (*Read the analysis, page* 442.)

A wheel with teeth, made to turn and to strike a piece of quill with every tooth, if moved slowly, will allow every tooth to be seen and every blow to be separately heard; but with increasing velocity the eye loses sight of the teeth, and the ear at last hears only a smooth continued sound, called a *tone*, of which the character changes with the velocity of the wheel.

In like manner the vibrations of a long harp-string, while it is very slack, are separately visible, and the pulses produced by it in the air are separately audible; but as it is gradually tightened, its vibrations quicken, and the eye soon sees only a broad shadowy line where it is moving, and the distinct sounds which the ear lately perceived run together, owing to the shortness of the intervals, and are felt as one uniform continued tone, which constitutes the note or sound proper to the string.

It is the elasticity of such a string which causes the repetition of the percussions, and therefore the continuance of the sound. Thus:—the string having been pulled at its middle to one side, and then let go, its elasticity carries it back quickly to the straight position; but by the time that it has reached this, it has acquired a momentum which, like the momentum of a vibrating pendulum, carries it to a distance nearly as far beyond the middle station, as that from which it came:

—it has to return therefore from this second deviation in the same way, by the action of its elasticity; but still passing the middle as before, it has again to return, and thus continues vibrating as a pendulum does, until the resistance of the air and the friction bring it gradually to rest.—As the vibrations of a string become quicker, the impulses given to the air by it are of course individually more forcible, and hence the sound becomes louder. Vibrations which are few and slow strike the ear very gently, as in the flapping of a pigeon's wing, or in the play of a switch. A large vibration just occupies the same time as a smaller, because the more that a string is bent, the more forcibly it is pulled back again by its elasticity: hence the uniformity of a musical tone.

From the resemblance in the motion of elastic bodies to that of a pendulum, almost all such may be made to repeat an impulse once given to them, and thus may become the means of producing a continued sound.

The most familiar instance of sounding vibration is that of an elastic cord extended between two fixed points, as in all stringed instruments of music: but it is producible in many other ways.—If a solid rod of steel, glass, or any other elastic substance, be fixed firmly at one end and left free at the other, and if this other be then pulled a little to one side of its station of rest, and be suddenly let go, it will seek its station again, and will go beyond it by the momentum acquired in the approach: it will then return, and continue the vibratory movement for a long time.—A boy at school sticks the point of his penknife into the bench, and by one touch makes it produce a continued uniform sound.—The prongs of a tuning-fork, or of the common sugar-tongs, vibrate and sound in the same way.—In the musical snuff-boxes and chimney clocks, the sounds are produced by the vibration of little rods of steel, fixed at one end, and placed together like the teeth of a comb.—The reed of a clarionet is a thin plate of elastic wood, made to vibrate by the passing breath, and as it stops the current of air at each vibration, it produces a repetition of pulses, or sound.—Elastic rods resting on supports at both ends, or suspended by their middle, will also vibrate. A musical instrument is made of pieces of glass laid upon two strings, and struck by a cork hammer. In the island of Java, a rude instrument of the same kind is made of small blocks or logs of hard elastic wood.—The half of a hollow sphere of elastic metal, very readily takes on a vibration, in which its form is constantly changing from the perfect round to the oval and inversely; there is consequently repeated percussion of the air, and a continued sound, and the thing is called a *bell.* It admits of variety of shape, and may be made of any elastic substance, as metal, glass, earthenware (buyers always ring earthenware to ascertain its soundness), and even of hard wood. The *Chinese gong* is a metallic vessel shaped like a common sieve, of which the vibration is very peculiar, and the sounds rousing and sublime.—The *drum* has a tense elastic membrane on which the blows of the drum-stick are received: its tone ceases quickly, because the motion of its broad surface is much resisted by the air.—In the flute, flageolet, organ pipes, &c. the air is forced through narrow passages, and is divided by sharp edges, in a way to suffer constant but perfectly regular condensations or interruptions; and hence the endless variety of sweet continued sounds which these contrivances are known to produce.

It is of no consequence to the perfection of a tone in what way the pulses of the air are produced, provided they follow with sufficient regularity: witness the pure sound produced by the motion of a fly's wing, supposed by many to be the voice of the insect. The clacking of a corn-mill, or the noise of a stick pulled along a grating, is not musical, only because the pulses follow too slowly. It is because elastic bodies vibrate with the regularity of the pendulum that their sounds are so uniform and clear.

Where a continued sound is produced by impulses which do not follow in regular succession, the effect ceases to be a uniform sound or tone, and is called a *noise*.

Such is the noise of a saw or grindstone—the roar of waves breaking on a rocky shore, or of a violent wind in a forest—the roar and cracking of houses or a wood in flames—the mixed voices of a talking multitude—the diversified sounds of a great city, including the rattling of wheels, the clanking of hammers, the voices of street-criers, the noises of manufactories, &c.: these elements, however, at last mingle with such uniformity, that the combined result is often called the hum of men, from analogy to the smooth mingling miniature sounds which constitute the hum of the bee-hive.

"*Grave and sharp sounds.*" (*See the analysis.*)

The difference of sounds depending on the different number of vibrations of the sounding body in a given time, divides them into classes: called *bass*, or *low*, or *grave* notes, for the slow vibrations; and *high*, or *shrill*, or *sharp*, for those that are quick.

The frequency of vibrations in strings increases with their shortness, lightness, and tension—for if a string be long or heavy, there is a greater mass of matter to move, and hence a slower motion; and if a string be slack, the force which pulls it, when bent, back to the straight line, is so much the less. It is found that a string of half a given length, or of one-fourth of a given weight, or of quadruple tension, vibrates twice as fast on any of these accounts.

These truths are familiarly illustrated on the violin. The low or bass string is thick, and made very heavy by being covered with metallic wire; the others gradually diminish in magnitude and weight, up to the smallest or treble. They are tuned to each other by being attached to pins, which on turning increase or diminish their tension; and the sound produced by each may be varied almost to infinity, by pressing it against the board in any place with the finger, and thus shortening the vibrating part.

An analogous law, as to weight and dimension of sounding bodies, holds with respect to bells, glasses, and reeds, and enables us to use all these in the construction of musical instruments.

3 "*When simultaneous or following sounds have simple relations to each other in the number of vibrations constituting them, as of half, third, fourth, &c. in the same time; the ear is strongly and pleasingly affected by the circumstance, and the sounds are said to be musically related to each other, or to be concords, while all others are called discords.*" (*Read the analysis, page* 442.)

Now that we understand the nature of sounds, we cannot hesitate to believe that the reason of the ear perceiving the relations called *concords*, and having pleasure in them, is because the pulses of such sounds heard together coincide so frequently. In a sound in which there are twice as many beats as in another, they will coincide at every second beat of the quicker: if they be as three to one, every third beat of the quicker will be the double one, and so forth; while if they have a more distant relation, as of nineteen to twenty, the coincidence occurring only once in twenty beats is not perceived at all, and the effect on the ear is discordant or grating.—The coincident or double pulses of two concordant sounds become the elements of a third sound, which is always heard with them, and is called their *grave harmonic*.

If a long musical string be made to sound, and the number of its vibrations in a given time be ascertained, we find that half of it will vibrate twice as fast; a third part, three times as fast; a fourth part, four times; and so on.

If the string of a violincello be made to vibrate by moving a bow very gently across it, near the bridge, there is heard not only the sound or note belonging to its whole length, but also more feebly, the subordinate notes belonging to the half, the third, the fourth, &c. beautifully mingling with the first sound, and forming with it a rich harmony. If the bow touch very lightly, and very near the bridge, the sweet subordinate sounds often swell with greater force, and overpower for a time the fundamental note; and, at that moment, if the string be carefully examined, it will be found to be vibrating, not as a whole, but in two, three, or four distinct portions, with points of rest between them; and little bits of paper thrown upon it will be shaken off from every other part except these. These harmonic sounds may also be produced at any time by touching the string lightly with the finger, at the points where we wish it to divide.

The sounds thus belonging to a single cord or string, and produced by its spontaneous divisions into different numbers of equal parts, constitute, when heard together or in succession, the simple music of nature herself. It is produced pleasingly, as just described, by the single string of a violincello, but in the most perfect manner by the instrument called the Æolian harp.

The Æolian harp is a long box or case of light wood, with harp or violin strings extended on its face. These are generally tuned in perfect *unison* with each other, or to *the same pitch*, as it is expressed; but when the harp is suspended among trees, or in any situation where the fluctuating breeze may reach it, each string, according to the manner in which it receives the blast, sounds either entire or breaks into some of the simple divisions just described; the result of this is the production of the most pleasing combination and succession of sounds that fancy has ever listened to or perhaps conceived. After a pause this fairy harp is often heard beginning with a low and solemn note, like the bass of distant music in the sky: the sound then swells as if approaching, and other tones break forth, mingling with the first, and with each other. In the combined and varying strain sometimes one sweet note predominates, and sometimes another, as if single musicians alternately led the band: and the concert often seems to approach and again to recede, until with the unequal breeze it dies away, and all is again at rest.—It is no wonder that the ancients, who understood not the nature of air, nor consequently even of simple sound, should have deemed the music of the Æolian harp supernatural; and in their warm and chaste imaginations, should have supposed that it was the strain of invisible beings from above, descended in the stillness of evening or night to commune with men in the heavenly language of soul intelligible to both. But even now that we understand it well, there are few persons so insensible to what is delicate and beautiful in nature, as to listen to this wild music without emotion; while to the informed ear it is additionally delightful from the fine illustration which it affords of those simple laws of sound which human ingenuity at last has traced.

As the simple scale of sound, called the *major chord*, which nature thus gives by the spontaneous dividing of a single string, has considerable vacancies in it, human taste or feeling, long before there was any theory of music, had joined to the notes of a chief chord, those of two others nearly related to it, of which additional notes, while part agreed, or were in unison with the tones of the principal chord, the remainder just served to fill up its larger intervals, and to complete a scale of gradual ascent. So truly natural is the scale thus formed, that it has arisen in all nations, however remote or unconnected; and an untutored individual, in attempting to raise his voice by regular steps, falls into it almost as readily as the learned professor. This scale has eight steps or notes, counting from any principal or fundamental tone, to that tone above it which vibrates twice as fast, or to that tone below it, which vibrates half as fast. These two notes are hence called the *octaves* above and below the *key note*, and the intermediate notes which fill up either octave, are distinguished as the *second*, *third*, *fourth*, &c. The numbers which express the relations of beats among the notes of an ascending octave, are $1\ \frac{9}{8}\ \frac{5}{4}\ \frac{4}{3}\ \frac{3}{2}\ \frac{5}{3}\ \frac{15}{8}\ 2$. The scale, however far extended, is a repetition of similar octaves, so that any note in it vibrates just twice as often as the corresponding note in the octave below, and half as often as that in the octave above. The lowest note which is perceptible to the human ear has about thirty beats in a second, and the highest, about thirty thousand; and there is included between these two, a range of nearly ten octaves. To certain ears the extremes of this range are inaudible, for some persons do not hear at all the sharp note of the grasshopper, or cannot distinguish between the lowest tones of an organ or piano, although their perception of intermediate sounds is very perfect. Few musical instruments comprehend more than six octaves, and a human voice has usually from one to three, the male voice being pitched an octave lower than the female.

If the intervals in the musical scale were all equal, a performer might choose indifferently any note as a fundamental or key note, and would only have to attend to the intervals above and below, according to their number; but, in fact, the third and seventh intervals in ascending from a key note must only be about half as large as the others; hence, in changing the key on any instrument, certain notes belonging to other keys are half a note too *flat* or too *sharp*, and must be changed accordingly: and hence, that an instrument may play in any key, all its larger intervals are divided into two parts. It is this little circumstance, ill understood, which gives a false appearance of complicacy and difficulty to musical science.

Melody, in music, is when notes having the simple numerical relations of beat which we have been describing are played in succession: *Har-*

mony is when two or more such notes are sounded together. The effect of both is delightfully increased by making the duration correspond with certain regular divisions of *time*. This gives to the ear a prescience, to a certain degree, of what is coming, and the pleasure follows of having expectation realized, as in the case of the metre and rhyme of poetry: it also enables the memory to retain musical combinations of sound—for the airs of the Æolian harp, which observe no *time*, cannot be repeated. The music of a single drum is that of time only.

Melody, *harmony*, *time*, and *varying intensity of sound* are the four constituents of music, and it seems that almost every state of mind has in some combination of these, an appropriate expression, intelligible to the general feeling of the human race. The exact relation between the movements of the animal spirits, as it has been expressed, or the fluctuating stream of excited feeling, and the varying flow of sound in a musical composition, is not well understood, but the fact of their correspondence and its consequences are most remarkable. Under many circumstances the association between the feeling and the musical expression is so strong, that the latter is often spontaneously betraying itself;—witness the almost constant humming, or low song, of some contented beings—the singing and whistling of careless childhood, and of the light-hearted rustic who lives among the beauties of nature — the heart-rousing strain of the hunter or warrior—the tender expression of many of the modifications of anxiety and sorrow.—And the musical sensibilities are by no means confined to man, for there is no expression more exquisite than in the song of the nightingale during the evenings of spring, or of the thrush and blackbird, amid the quiet retreats of our woodlands: and the music of these untutored songsters contains the same elements of expression as our own.

The *accompaniment* of an air which is afforded to a singer by one or more instruments, and which is so pleasing, is chiefly the sounding simultaneously, in a subdued manner, the other notes of the chords to which the several vocal notes belong. *Duetts* and more complicated *concert-pieces* spring from the same source: and highly cultivated musical sense can even follow and enjoy several melodies played together.

Musical notes, by whatever instrument produced, have to each other the same numerical relations in the beats or vibrations which constitute them. The different qualities of tone, therefore, from different instruments, can only depend on the peculiarities of the single beats, as to whether they are sharp or soft, strong or weak, &c. Such is the extraordinary nicety of perception which the ear possesses in this respect, that it can not only distinguish different kinds of instruments playing the same note, but different instruments of the same kind, even to the extent, for instance, of recognising each one of a hundred human voices singing the same strain. One of the greatest charms of concert music, is that the voice and the different instruments may take up successively the parts of the strain suitable to their individual expression—the flute and clarionet, for instance, breath softness; the trumpet and drum arouse; the harp rolls out its brilliant chords; the violin leads the flowing sound through rapid and endless variety; and so of the rest.

That there might be correspondence in instruments when played together, and a known pitch when played apart, it became necessary to fix on some tone or number of vibrations as a point of comparison. Hence *tuning-forks* have been made with length of prongs calculated to produce some certain note; and the note of the same name on any instrument being tuned in unison with this, the others are easily adjusted, according to the harmonic relations above explained.

Almost every substance or contrivance that can produce a uniform continued sound may enter into the composition of a musical instrument: hence the almost endless variety which the world has seen. The chief classes are *stringed instruments*, *wind instruments*, and *bells* or *rods*.

Of the stringed instruments, we may mention the *harp*, the *lyre* or *lute*, the *guitar*, the *violin* of all sizes, and the *piano-forte*. The harp, lyre and lute were the inventions of antiquity, and have brought down with them to the present times, a thousand delightful associations. They awakened to inspiration the bards and poets of the young world, and they were the beloved companions of many of the noblest minds of succeeding times. Their great charm was in their power to heighten the emotions produced by music's twin sister poetry; and the effects seem to have been magical.—The other instruments mentioned are of comparatively modern invention, particularly the piano-forte; and their perfection has assisted in carrying the *practice* of music to degrees of complicacy and difficulty, of which antiquity dreamt not. It is a question, however, whether the style of the music now in vogue prove not rather a degeneracy than a desirable refinement of musical taste. Music is a language of nature, intelligible at once to all susceptible minds, and in a degree, even to inferior animals; but modern art is attempting to make of it an artificial and conventional language, in which there may be fashion and change. Its ornaments and accompaniments are now often so overwhelming, that the *melody*, in which the idea and sentiment really reside, is almost lost; and the unpractised ear, particularly if listening to an *organ*, often discovers only an unmeaning succession of chords. And when, in singing, the natural simplicity of melody is abandoned, by straining to execute with the voice the complicated movements which belong properly to instrumental accompaniment, the attempt destroys the poetry, by either rendering the words inaudible, or sacrificing their natural expression to some supposed appropriate expression of the ornamental music. These considerations may account in part for the insensibility of so many persons to what *is now called* excellent music: while it must be allowed that the changed state of society has also its influence. Music is an appropriate expression rather of the high mental excitement which existed among the wars, and contentions, and uncertainties of the ancient Greek states, than of the calm confidence and security which attach to modern civilization. — The tricks on the voice and on instruments, now so common, rank truly with tumbling and rope-dancing, and are no more natural music than these are graceful gesture. And when we hear noted professors avow their inability to sing a simple ballad, or to play an unadorned melody, may we not conclude that the natural sense of music has left them, as the relish for nature's fare has left the morbid epicure?

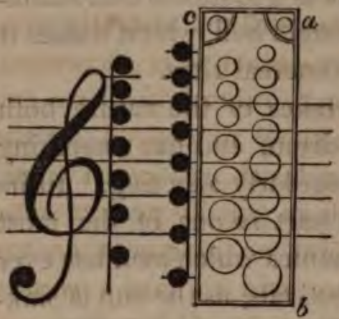
The *guitar*, as affording an accompaniment to vocal music, has many advantages. It is not too loud, although the strains are distinct: it admits of very touching expression; it is very easily learned by all who should attempt to learn music at all; it is portable and cheap. The great facility of accompaniment on it depends on this, that the player is able by one position of the hand to touch the strings so that the sounds of all shall belong to the same chord: — three positions, therefore, for one key, produce all the notes and chords which a simple accompaniment requires; and the hand soon falls into these so readily, that the player is hardly sensible of exerting volition.

Wind instruments are, the *flute*, the *flageolet*, the *organ*, the *clarionet*, the *hautboy*, the *horn*, the *trumpet*, &c. The pitch or tone of a wind instrument, just as of a musical string, depends upon its length; and the vibrations causing the sound seem to be waves or condensations of air passing from the mouth to the extremity of the tube, and back again; which are therefore more frequent, as the tube is shorter. It appears also, that on blowing more strongly, the air in the tube divides into separate vibrating portions, as a string divides, and produces thus all the harmonic sounds belonging to the fundamental note. By blowing into a common German flute, for instance, it is possible to produce five ascending harmonics without moving the fingers at all. The music of a trumpet is limited to these five notes: but in the flute, and other instruments with holes, the effective length of the tube is calculated from the upper end to the nearest hole left open; and each length has its harmonics.—The sounds of the human voice are the sweetest of all, and are produced by the vibrations of two delicate membranes, placed at the top of the windpipe, with a slit or opening left between them, called the *glottis*, for the passage of the air. The tones of the voice are grave or acute, according to the varying tension of these membranes, and to the size of the opening.—In the *organ* there is a pipe for every note, and wind is admitted to the pipes by the action of keys, like those of a piano-forte. The organ may be played also very perfectly by a barrel, made to turn slowly under the keys, and having pins projecting from it at the required situations to lift the keys in passing. Very complicated pieces of music are thus set on barrels, but at great cost of study and labour, and therefore of money: now a plain barrel, made to turn near the keys of an organ during performance on it by the hands, might be made to record with mathematical accuracy every touch of the most finished player, by receiving marks from the keys as they rose: and to repeat any performance, therefore, however delicate and exquisite, it would only be necessary to drive pins into the barrel where the marks remained, and to make these afterwards lift the keys. The author does not know that this thought has ever been acted on, or indeed has ever occurred before.

Bells are often conjoined in sets having the musical relations, and their music to some persons is very agreeable. There is a loudness and solemnity in the tolling of a single bell which makes it a fit accompaniment of funereal rites.

The *Chinese gong* partakes of the nature both of a bell and of a great drum, and has something in its sound which is singularly affecting. In its own country it bears a part in one of the most imposing religious ceremonies which man has ever imagined. On certain festivals, as the sun is sinking in the west, the whole population of China,—a host of a hundred millions,—issues forth, under the single canopy of heaven, to testify, amid the thunder of gongs and the continued discharge of fire-works, that adoration and gratitude towards the Deity, which human nature, when undepraved, always feels, and eagerly seeks to express, however blind as to the sublime simplicity of religious truth.

Glass bells or goblets sound still more perfectly than those of metal, and by gentle friction on their edges with a bow or the wetted finger, their tones may be continued for any length of time, and may be made to swell and diminish like the human voice or the notes of a violin. A set of glasses, therefore, attuned to each other, according to the harmonic scale, becomes for certain species of music, the most perfect of all instruments. It is in fact an Æolian harp at command. Dr. Franklin first constructed a set; and he doubled the long line of glasses upon itself, and placed the half-notes as outside rows. The author, however, during some experiments on sound, found the *zig-zag* arrangement here represented to possess many advantages. The small open circles represent the mouths of the glasses standing in a box *a b c*, and the relation of the glasses to the written musical notes is shewn by the common music lines and spaces which connect them. The learner discovers immediately that one row of the glasses produces the notes written *upon* the lines, and the other row the notes written *between* the lines; and he is mentally master of the instrument by simple inspection. This arrangement renders the performance also very easy, for the notes most commonly sounded in succession are contiguous. And the relations of the notes forming a tune are so obvious to the eye, that the theory of musical combination and accompaniment is soon learned, so as much to



facilitate the practice. The set of glasses here represented has two octaves, and with the additional *flat seventh* and *fourteenth*, seen at *a* and *c*, it is capable of playing the greater part of our simple melodies. The player stands at the side of the box between *a* and *b*, and has the notes ascending towards the right hand, as in a piano-forte.

Musical ear.

Philosophers have not yet been able to account for a remarkable difference among individuals, as regards their perception of the musical relations of sounds. Many persons, without understanding anything of acoustics, can still tell instantly whether various notes heard together or in succession, have the relations to each other which we call musical, and which we know to depend on the comparative numbers of beats in a given time: and there are others with an equally perfect sense of hearing, who can form no judgment on the subject. The former are said to have a *musical ear*, and the latter to want it. Cultivation will raise mediocrity to considerable expertness, but cannot bestow the faculty where it is absent.—There is a misconception on this subject, which is a source of mortification to many on one side, and a cause of arrogance to many on the other. We hear it said, that the possession of a musical ear, or the power of distinguishing notes, is the indication of all the finer sensibilities of the mind, while the want of it proves an opposite deficiency; and Shakspeare's opinion of him "who has not music in his soul," is often triumphantly cited as applicable to all who want the distinguishing ear.

Now, in truth, many of those who signally excel as musicians are deficient in almost all else that humanity reveres, while many who have no musical discrimination are otherwise examples of excellence, and may be exquisitely sensible to other beauties and harmonies of nature even as regards sound. They are not deaf, for instance, to the music of spring, when all nature bursts forth in voice of rejoicing, or to the awful music of the storm :—they feel the music of silence in a lone wood, after being accustomed to the unceasing stir of multitudes—or of the stillness of night in a great city, where the astronomer contemplating the wondrous spheres above, hears only the tongues of passing time in the church-towers, or the call of watchmen, faintly sounding in the distance. Many excellent poets have had no musical ear.—Often the charm of music is as much from early associations as from peculiar aptitude in the individuals. The effects are well known of the Swiss airs, when heard by native Swiss in foreign lands; and, indeed, of the national melodies of all countries—for it is not in nature, that at any period of life, or in any clime, a man should cease to deem those modulations lovely which in his infancy and childhood he learned from a mother's voice: the mother whose affection was so long around him as a shield, whose tears fell to chide his errors, and to reward where there was promise of virtue, whose steady judgment was his guide, whose faultless life was his example, and who in all things to him was the personification of God's goodness on earth.

It is the prejudice with respect to musical ear and musical taste of which we are now speaking, which, in the present day, condemns many young women possessed of every species of loveliness and talent except that of *note-distinguishing*, to waste years of precious time in an attempt to acquire this talent in spite of nature; and when they have succeeded as far as they can, they have only the merit of being machines: their performance is still as little pleasing to true judges, as would be the attempt of a foreigner, knowing only the alphabet of a language, to recite pieces of expressive poetry in that language. Such persons, when liberty comes to them with age or marriage, generally abandon the offensive occupation; but tyrant fashion will have their daughters to run the same course. The waste of time now spoken of, is only one of many evil consequences which arise from the prevailing false notions with respect to music, but the subject cannot be farther entered upon in this place.

"*The trembling which causes the sensation of sound spreads in all bodies, solid or fluid. (Read the analysis, page* 442.)

As air consists of material particles held far apart from each other by the repulsion of heat among them, we can conceive how an impulse given to a certain portion of the particles is transmitted to those beyond, by the increase of repulsion as they approximate; and from the second layer in the same manner to a third, and so on. And as in fluids the particles all mutually rest against, or repel each other, we can conceive why a motion produced in any part of a mass should be felt in every direction. The explosion of gunpowder, in which there is an instant formation of a quantity of air, gives a shock all round which spreads as a spherical wave to a great distance.

Although material particles in the form of liquid or solid are so much nearer to each other than in the form of air, we still have many proofs, as stated at page 228, that they are not in absolute contact, and we therefore see the reason why the impulses producing sound should be transmitted through a liquid or solid as through air, and even, more quickly and forcibly than in air.

Instances of air carrying sound were given at page 444.—As further examples, we may cite the cases of what are called *sympathetic sounds.* Every elastic body being sonorous, that is to say, being fitted to tremble when struck, with a certain frequency of oscillation, depending on its weight and shape, if the air around it be made to tremble by any cause, in a tone which it is fitted to take on or produce, it immediately begins to tremble in unison; and its motion or sound will continue after the original cause has ceased.—Almost any sound produced near a piano-forte with the dampers raised finds a responsive string. Bits of paper strewed upon the wires are soon shaken off by those returning unisons or octaves to any tone sounded in the vicinity, but remain on the others. —A harp or guitar in a room with talking company, is often mingling a note with their conversation.—Wine glasses or goblets may be made to tremble, and even to fall from a table, by sounding the note accordant to their own, on a violincello near them.

Sounding bodies vibrate much more quickly, or have sharper tones, if placed in light hydrogen, than in common air; and more quickly in common air, than in any of the heavier gases: because the lighter the air, the less is the resistance to a body moving in it.

That water is also a vehicle of sound, is proved in the distinctness with which the blows given by workers around a diving-bell are heard above, and by the fact that fishes hear very acutely, &c. A bell will ring under water, but it produces a much graver sound than in the air.

The following are instances of sound conveyed by solids.—A scratch of a pin at one end of a log of wood is distinctly heard by the ear applied at the other end, although through the air it is not at all audible.—Savages often discover the proximity of enemies, or of prey, by applying an ear to the ground and hearing their tread.—The approach of horsemen at night is easily discovered in the same way.—The report of a cannon placed on ice is carried much farther by the ice, than by the air around.—The awful muttering of earthquakes is merely sound of subterranean explosions, conveyed by the solid earth from amazing distances.—In the military operation of mining, or cutting a way under ground for the purpose of entering a citadel or blowing up fortifications, the approach of the enemy is often discovered by the subterranean sound of the pioneers' tools.

The readiness with which solids receive and transmit sound is further seen in the fact, that a small musical box, if held in the hand, is scarcely audible, but if pressed against a table or a door, rivals a little harp. The vibration communicated from the box pervades the whole of the wood, and the extended surface then acting on the air increases the effect. The construction of violins, harps, guitars, &c., and of sounding-boards generally, is governed by the same law. In the dancing-master's *kit* or small fiddle, which he carries in his pocket, there are the same strings and the same bow as for a violin, but it has very little sound, because the extent of its surface is so small. A heavy piece of metal called a sourdine, when fixed upon the bridge of a violin, damps the sound, because it is a dead mass resisting the motion of the elastic wood.

It is easy to ascertain whether a kettle boils, by putting one end of the poker on the lid and the other end to the ear: the bubbling of the water appears louder than the rattling of a carriage in the street. A slight blow given to a poker, of which the end is held to the ear, produces a sound which is even painfully strong.

The fact of solids conveying sound so much more perfectly than air, has lately been applied in medicine to useful purposes. Dr. Laenec of Paris proposed some years ago to listen to what was going on in the interior of the body, and of the chest particularly, by applying one end of a wooden cylinder, which he called a *stethescope* or *chest inspector*, to the surface, and resting the ear against the other end. The results of this happy thought have been very important.

The actions going on in the chest are, the entrance and exit of the air in respiration, the voice, and the motion of the blood in the heart and blood-vessels; and so perfectly do all these declare themselves to a person listening through the *stethescope*, that an ear once familiar with the natural and healthy sounds, instantly detects certain deviations from them. Hence this instrument becomes a means of ascertaining diseases in the chest, and their varieties, almost as certainly as if there were convenient windows for visual inspection. And when it is considered that a fourth or fifth part of the inhabitants of Europe die of chest diseases, such as inflammations, abscesses, consumptions, dropsical collections, aneurisms and other affections of the heart and blood-vessels, each of which requires an appropriate treatment, the importance of the stethescope may be judged of. By many medical men this instrument was ridiculed at first as quackery and nonsense, and very many have yet to learn the use of it. May not both of these facts be attributed to the error which has existed in medical education up to the present time, of leaving a majority of professional men without that knowledge of the general laws of nature, which should enable them to appreciate at once any means likely to be useful in their art, from whatever quarter it may be offered?

"*Velocity of sound.*" (*See the analysis.*)

The velocity of light is such (see the chapter on optics), that for any distance on earth, its passage may be regarded as instantaneous. The velocity of sound is considerably less.—If a woodman be observed at his occupation on the hill, his axe is seen to fall some time before the sound of his blow reaches the ear.—The flash of a gun fired at a distance, is seen long before the report is heard.

Most accurate experiments have been made to ascertain the velocity of sound; and it is found to be 1,142 feet per second in air, or a mile in about four seconds and a half; and it varies little either with the density or temperature of the air.

By noting then how long the flash of a gun is seen before the report reaches the ear, we learn the distance of the ship or battery from which the gun is fired. A chasing ship may thus often discover whether she be *nearing* or not the object of her pursuit. In the same manner the distance of thunder may be ascertained: and the reason of the long continued roll of thunder is, that although the lightning darts instantly through a chain of clouds, perhaps of miles in length, the claps or explosions at each interruption of the chain are only heard successively, as the sound arrives at the ear. The pulse at the wrist of a healthy man is a convenient measure of time for ascertaining distances by the motion of sound: each beat is nearly a second, and therefore indicates a distance of nearly a quarter of a mile.

A line of muskets fired at the same instant cannot appear a single report to any person, unless he be in the centre of a circle, of which the line forms a part.

An extended orchestra of musicians cannot be heard equally well from all situations.

Wind affects the velocity of sound moving towards a certain point, just as the current of a tide affects the motion of a sailing ship. The effect is readily perceived in a stormy night, according as the wind happens to bring or to resist the coming sound of distant bells.

Sound decreases from the centre where it originates, according to the same law as light; that is to say, at double distance it is only one-fourth part as strong.

By confining it, however, in tubes, which prevent its spreading, its force diminishes much less rapidly, and therefore will extend to much greater distances.—In many houses and manufactories pipes for this purpose are now made to lead to all parts, and on ringing a bell to attract attention, orders are given verbally to any distance.

Sound travels about four times quicker in water, and from ten to twenty times quicker in solids, than in air. The blow of a hammer given to a wall may be heard twice, *viz.* almost immediately, by an ear applied to the wall, and a little after, through the air.

"*Reflection of sound.*" (*Read the analysis, page* 442.)

As a wave of water turns back at a smooth wall or obstacle, and at any distance from it after the reflection, is just what it would have been at the same distance beyond, only moving in an opposite direction; so the pulses or waves of sound are regularly reflected from flat surfaces, and produce what is called *Echo*. Such flat surfaces of nature's work are found only among the rocks and hills; hence the beautiful fiction of the ancient poets, that Echo was a nymph who dwelt concealed among the rocks. Science has now disclosed the secret of the viewless echo; but who does not vividly recollect the wonder and delight with which he has listened, in the morning of his days, to his shrill call returned to him from some bold precipice, across the plain or the river, or sent down to him again from the vaulted roof of ocean's caves!

The quickness with which an echo is returned depends of course upon the distance of the reflecting surface; and, as sound travels 1,142 feet per second, a rock at half that distance returns a sound exactly in one second. As many syllables as can be pronounced in a second will be repeated distinctly in such a case, while the end of a longer story would mix with the commencement of the echo. The breadth of a river may thus be ascertained where there is an echoing rock on the farther shore. A perpendicular mountain side, or sublime cliffs such as skirt the British coasts in many parts, return an audible echo of artillery, or of thunder, to a distance of many miles.

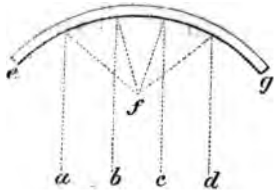
If two bold faces of rock be parallel to each other, a sound produced between them is repeated often, playing like a shuttlecock between them, but becoming more faint each time until it is heard no more.

The resonance of rooms depends on this continued reverberation. It often increases the effect of music by converting a simple melody, which is a *succession* of notes, into a harmonized piece, where each note is *accompanied* by softer accordant tones; and a young flute-player is often first charmed with his own music when he finds himself playing a duett with echo in a cave or under a spacious arch—but resonance injures the distinctness of speech, so as even in some ill-contrived halls of assembly, or theatres, to render the articulation unintelligible.

It is worthy of remark, that every apartment or confined space has a certain musical note proper to it, which depends upon the number of pulses or repetitions of a sound produced in a given time by the returns from its walls. The velocity of sound being uniform, this number must depend on the size of the apartment.

There is a curious effect of echo which both illustrates the nature of the phenomenon, and proves that a tone or musical sound is merely a repetition of pulses following each other very quickly. Iron railings are generally formed of square bars, of which each side, therefore, is a plane surface, and may produce an echo. Now a sound, such as the sharp blow of a hammer, occurring near the end of such a railing, is echoed to the other side by every bar in it; and as the echoes do not return all at once, but in regular succession according to the increasing distances of the bars, the consequent regular succession of slight pulses, with uniform and small intervals, affects the ear, not as the echo of a single blow, but as a continued musical tone, the pitch of which depends on the distance of the bars from each other.

That an echo may be perfect, the surface producing it must be plane, and of some regular form, for the wave of sound rebounds according to the same law as a wave of water, or the rays of light, or an elastic ball, *viz.* perpendicularly to the surface, if it fall perpendicularly, but if it fall obliquely, or on one side of the perpendicular, it departs with an equal degree of obliquity on the other side. To express this very important law shortly, we say that "the angle of incidence is always equal to the angle of reflection."—According to this law, any irregular surface must break an echo; and if the irregularity be very considerable, there can be no distinct or audible reflection at all. And any regular concave surface, as *e g*, may concentrate sound, and bring all the waves which fall upon it, as from *a b c d*, to the same centre or *focus* as at *f*.

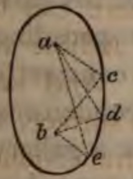


We hence see the reason why echo is much less perfect from the front of a house which has windows and doors, than from the end, or any plane wall of the same magnitude,—and why the resonance of a room is very imperfect when it contains curtains, carpets, and other furniture, or a crowded assembly. Halls for music have generally plane bare walls. Theatres for the drama, again, have boundaries broken in all ways by rows of boxes, and various ornaments.

The concentration of sound by concave surfaces produces many curious effects in nature and in art.

There are remarkable situations where the sound from a cascade is concentrated by the surface of a neighbouring cave, so that a person accidentally bringing his ear into the focus, is astounded, as if the universe were crashing around him: and a chair may be placed in the cave so that a person sitting down must bring his ear into the focus.

The centre of a circle is the focus in which sound issuing from the centre is again collected after reflection: hence the powerful echo near the centre of a round apartment. An *oval* has two centres or foci—one towards each end, as *a* and *b*—and the nature of the curve is such, that sound, or light, or heat, issuing from one of the foci, is all directed after reflection, as at *c*, *d*, *e*, &c., to the other. Hence a person uttering a whisper in one focus of an oval room is very audible at the other, although not at all to persons placed between. Such a room may be called a *whispering gallery*. Concave surfaces facing each other, as two alcoves in a garden, or covered recesses on opposite sides of a street or bridge, will enable persons seated in their foci to converse by whispers, and without being overheard in the intermediate space.



The reason why a tube conveys sound so far, is, that its sides confine or compress, by a continued reflection, the waves of sound which in the open air would quickly spread laterally and be dissipated. And the reason that the plane surface of a smooth wall, or of water, &c., also conveys sound so far, is, that it similarly prevents the lateral spreading and dissipation, although only on one side.—Persons far apart may converse along a smooth wall.—The clear voice of a street-crier, in a town situated on the border of a lake, may be heard across the water in a calm evening, at a distance of more than five miles—the sound of bells, of course, is audible much farther.—And in the stillness of night, a steam-boat, by the splashing of its wheels, announces its approach to persons waiting, when it is yet fifteen miles from the harbour.

If a sound-reflecting surface be curved inwards, that is, concave, it not only prevents the spreading of any sound which passes along it, but is constantly driving the external part inwards and condensing it. Hence in a circular space, such as a gallery under a dome, persons close to the wall may whisper to each other at all distances.

An *ear-trumpet* is a tube wide at one end where the sound enters, and narrow at the other where the ear is applied: its sides are so curved, that according to the law of reflection, all the sound which enters is brought to a focus in the narrow end. It thus increases manyfold the intensity of sound reaching the ear through it, and enables a person who has become deaf to common conversation, to mix again with pleasure in society.

The concave hand held behind the ear answers in some degree the purpose of an ear trumpet, and in a very large theatre is sometimes useful to persons of the quickest hearing. The wide spread concave sail of a ship has sometimes collected sound to a focus so perfectly, as to render audible the sound of bells a hundred miles distant. A machine, therefore, might be constructed having the same relation to sound that a telescope has to light.—A notorious instance of a sound-collecting surface was the *ear of Dionysius*, in the dungeons of Syracuse. The roof of the prison was so formed as to collect the words, and even whispers of the unhappy prisoners, and to direct them along a hidden conduit to where the tyrant sat listening.

The *speaking trumpet* is made according to the same law of reflected sound, so as to direct the strength of the voice to a particular point. The sea captain uses it to send his orders aloft, where the unaided voice would be lost in the noise of the wind and waves—or to hail ships at a distance. A similar form of mouth is used for the *bugle horn* and common trumpet, and fits them to sound the note of command amid the uproar of contending armies.

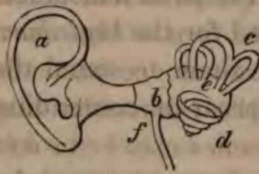
Some amusing effects have been produced by operating on sounds with tubes and concave surfaces. What was termed the *invisible girl*, was a contrivance where the questions of visitors were caught by a concealed concave, and carried to the director at a distance; and his replies, as in the whispering gallery, became audible to the inquirers alone.

The concave, undulating, and perfectly polished surface of many sea shells, fits them to catch, and concentrate, and return the pulses of sound that happen to be trembling about them, so as to produce that curious resonance from within, which so closely resembles the sound of the distant ocean—so closely, that the spirited boy, after studying the interesting stories of voyagers which paint dangers to be nobly braved, and charms of nature to be seen in distant lands, often feeds his imagination with the voice of the shell, and fancies himself already riding among the billows.

The animal ear,

So admirably adapted to perceive the evanscent tremblings of the air, has of course strict relation to their nature, as now explained. Its parts, and the progress of sound to the sentient nerve may be simply described as follows.

1st. There is a wide-mouthed tube or ear-trumpet *a*, for catching and concentrating the waves of sound. It is moveable in many animals, so that they can direct it to the place from which the sound comes.



2d. The concentrated sound falls upon a membrane like the top of an ordinary drum, covering the *tympanum* or *drum of the ear b*, and causes it to vibrate. That its motion may be free, the air contained in the drum has free communication with the external air, by the open passage *f*, called the eustachian tube, leading to the back of the mouth. A degree of deafness ensues when this tube is obstructed, as by wax, and a crack or sudden noise is generally experienced when the obstruction is removed in the effort of sneezing or otherwise.

3d. The vibrations of the membrane of the drum are conveyed farther inwards by a chain of four little bones (not here represented), reaching from its centre to the *oval door or window* of the labyrinth.

4th. The labyrinth, or inner compartment of the ear, over which the nerve of hearing is spread as a lining, is full of water; and therefore, by the law of fluid pressure, when the force of the moving membrane of the drum, acting through the chain of bones, is made to compress the water, the pressure is felt instantly over the whole cavity, as in a hydrostatic press.—The labyrinth consists of the *vestibule e*, the three *semicular canals* c, and a winding cavity, called the *cochlea d*, like that of a snail-shell, in which fibres, stretched across like harp strings, constitute the *lyra*.—The exact uses of these various parts are not yet perfectly known. The membrane of the tympanum may be pierced, and the chain of bones may be broken without loss of hearing. Considerable diversity of form and dimension is found in different animals. The bone containing the cavities of the ear is the hardest in the body, and is the first formed.

The ear has the power of judging of the direction in which sound comes.

When horses or mules march in company at night, those in front direct their ears forward; those in the rear direct them backward; and those in the centre turn them laterally or across; —the whole troop seeming thus to be actuated by one feeling, which watches the general safety.

The intensity of sound is to the ear a measure of distance.—In a windy night the sound of a distant bell may be brought so quickly, that it has not yet had time to spread and be weakened; and a person is often roused from a reverie by its unusual loudness and apparent nearness.—When a stormy wind blows directly upon a coast, and rolls the great waves in upon the beach, or among the rocks, the countryman living far inland hears the uproar, as if the ocean had burst its boundaries, and were pouring in upon the land.—The scene-contrivers at our theatres heighten the illusion of an approaching procession, by letting the accompanying music be first heard from a closed chamber or in a feeble tone, and afterwards making it gradually louder and louder. To the imagination already excited, perhaps to the highest pitch, by the drama of some divine mind, the advancing host is thus more vividly pourtrayed, than by any other possible expedient; and when at last with the thunder of drums and trumpets from the front of the stage the troop also appears, the effect is complete.—It is the varying loudness of the music of the Æolian harp which produces the feeling that the heavenly choir is sometimes approaching and sometimes receding.

CHAPTER III.

SECTION V.

DOCTRINES OF FLUIDITY IN RELATION TO ANIMALS.

In the preceding sections, occasional illustrations of the laws of fluidity have been taken from the animal economy: but there are many other particulars of the same class, and of great interest, which it is convenient to consider apart, under the separate heads of, 1st. *The circulation of the blood;* 2d. *The respiration and voice;* 3d. *The digestion;* and 4th. *The pelvic phenomena.* It is important to remark here, that this section cannot be understood by him who is ignorant of the preceding ones.

PART I.

THE CIRCULATION OF THE BLOOD.

Perhaps there is nothing more remarkable in the progress by which man has arrived at his present knowledge of the universe, than the fact that it is only two hundred years since he understood that the blood in his own and in other animal bodies is constantly circulating. And England claims as one of her sons, the man whose powerful intellect at last established this truth, in opposition to strong appearances, and to the most fixed prejudices. Dr. Harvey published his proofs in the year 1619. If we try to imagine what that science of medicine could have been which took no account of a fact, on which, as a basis, the whole fabric of certain physiology must rest, we are prepared for what the history of medicine exhibits of the writhings of human reason, in attempts to explain and to form theories, while a fatal error was mixed with all its suppositions.—The chief circumstance which prevented the earlier discovery of the circulation was, that on examining dead bodies, the arteries were always found empty of blood; and this was the reason, also, of these vessels being called *arteries*, that is, *air tubes*.

We now know, that as the Thames water spreads over London in pipes, to supply the inhabitants generally, and to answer the particular purposes of brewers, bakers, tanners, and others, and is then in great part returned to where the current sweeps away the impurities; so, nearly, in the human body, does the blood spread in the arteries from a central vessel in every direction, to nourish all the parts, and to supply material of secretion to the liver, the kidneys, the stomach, and other viscera, and returns from these by the veins, towards the heart and lungs, to be purified, and to have its waste replenished, that it may again renew its course.

The circulation may be more particularly described thus. From the left chamber or *ventricle* of the strong muscular mass the *heart*, a large arterial tube arises, called the *aorta;* and by a continued division or ramification, opens a way for the bright scarlet blood to every the minutest part of the living frame: the extreme divisions or twigs are so small, that they are called *capillary* or hair-like tubes. The blood at the terminations of these having answered the purposes of general nutrition, &c., by which it loses its bright colour, enters the commencements of the *venous tree* or returning channel; and gliding successively from smaller to larger branches, it returns towards the right chamber or ventricle of the heart, requiring purification and partial renewal. If the great arterial and venous systems of the body be considered as *twin trees*—the *scarlet* and the *purple*, with meeting and corresponding branches, and with trunks springing from the opposite sides of the heart, it will appear that they again meet or inosculate by their extreme roots, and thus form a circular channel. The root of the venous tree issuing from the right chamber of the heart, is called the *pulmonary artery*, and that of the arterial tree, returning to the left chamber, the pulmonary vein. They both ramify in the spungy masses, called the lungs, which, indeed, are chiefly composed of them. Fresh material for the blood brought from the *digestive organs* by the *absorbents* and *thoracic duct*, is constantly pouring into a large vein near the heart, and is completely mixed with the dark blood by violent agitation or *churning* during its passage through the heart. On leaving the right ventricle, the mixture is strained through the minute ramifications of the vessels in the lungs, and at the same time is exposed to the action of the air which enters the cells of the lungs in respiration. By this action the dark purple blood is converted again into the pure scarlet, and when thus changed, and having reached the left chamber or ventricle, it is ready to set out on its journey as before, charged with new life and nourishment. The two chambers or ventricles of the heart have each an anti-chamber or auricle (so called from an external resemblance to a dog's ear), into which the blood is first received from the veins, and there are valvular doors, which allow the blood to pass readily from auricle to ventricle, but oppose its recoil during the contraction of the ventricles. There are valves also in many parts of the veins, to secure the natural course of the circulation. Besides the important change or purification which the blood undergoes in passing through the lungs, its composition is much influenced by the action of the kidneys, of the exhalants of the skin, and of the liver: the two former relieve it from superfluous moisture and salts, the last, from a large quantity of matter in the form of bile.

The description given above of the circulation of the blood is only an outline, and yet by shewing the manner in which fresh matter enters, it contains more than Harvey knew of the subject. In this department, as in most others, knowledge has advanced from what is very general and vague, to what is more particular and precise; and just as the general nature of steam was known long before it served in steam-engines; and as the period of the moon's revolution had been observed for thousands of years before the fluctuations in her velocity could be calculated, in a way to make her the mariner's best guide in his courses across the ocean,—so when Harvey had proved the simple fact of the circulation of the blood, he had left much yet to be done, by observing minutiæ, and reasoning from them, to render the knowledge available for the many useful purposes which it is calculated to answer. It is within a few years only, that the importance of the subordinate circumstances has been fully appreciated; as evinced by the numerous works which have been composed to elucidate them; but many of these have served only to prove that if the difficulties were to be solved by natural philosophy, medical men in general had not yet studied it enough to be able to use it successfully. It will be attempted in this section to place certain important points of the subject in a clear light, and by referring directly to the general laws of nature, explained in the body of the work, to settle existing disputes on some of them, and to remove remaining doubts on others.

The fact of the circulation of the blood being once admitted, an enquirer who contemplates the apparatus by which it is effected, is led by the general analogies of nature to conceive—1st. That the ventricle of the heart, at each contraction, empties itself into the great artery;—2d. That the consequent jet causes a wave to pass along to the extremities of the simply elastic arterial tree, producing everywhere what is called the pulse;—3d. That the force of the heart, acting along the arteries, forces the blood through their open capillary extremities into the commencing veins, and along the veins back to the heart again. Now Harvey believed that these propositions completely described the circulation. But the following facts, and others, ascertained since his day, not exactly squaring with them, farther investigation has become necessary.—1st. The pulse, instead of being a *distinctly progressive* wave, is almost as instantaneous over the whole body as a shock of electricity;—2d. The arteries are all found empty after death; and if an artery be tied in the living body, the part beyond the ligature, although the action of the heart of course cannot reach it, is soon emptied through the capillaries into the veins;—3d. Although the rapidity of the blood's passage through the capillaries varies very much, it does not vary in accordance with the changes in the force of the heart's action. In analysing this subject, it is convenient to follow the blood round from the heart to the heart again through the three stages, of 1st. *The arteries;* 2d. *The capillaries;* 3d. *The veins.*

Motion of the blood in the arteries.

The contractions of the heart inject the blood into the arteries with force maintaining such a tension in them, that, according to the interesting experiments of Dr. Hales, recorded in his *Statical Essays*, if the artery of a large animal like a horse be made to communicate with an upright tube, the blood will ascend in the tube to a height of about ten feet above the level of the heart, and will afterwards continue there, rising and falling a few inches with each pulsation of the heart. Now a column of *ten* feet, as explained at page 234, indicates a pressure of about *four and a half* pounds on a square inch of surface, and this is therefore the force of the heart urging the blood through the extreme arteries into the veins. The opposing tension of the veins is much less, because, as will be explained under the proper head, the blood readily escapes from them into the heart: Hales found it generally to be such as to support a column a few inches higher than the level of the heart. In smaller animals Dr. Hales found the tension of artery and vein to be less than in large ones; and the ratios deduced for the human body, under ordinary circumstances, were eight feet column, or nearly four pounds per inch for the arteries; and half a foot column, or a quarter of a pound per inch for the veins. The first of these quantities, however, is considerably above the truth, and the other below it, on account of the obstruction which the inertia of the long column of blood in the tube offers to any sudden change.

Arteries examined after death are found to consist of, 1st. an outer coat of strong *elastic substance;* 2d. a middle coat of *circular fibres;* and 3d. an inner coat of *smooth lining membrane.* Their elasticity, or power of resisting change of dimension, and of returning to a middle state from either dilatation or compression, being the most obvious property, because remaining in the dead artery, was that first attended to. Minute observation of the phenomena of life has since determined the following facts, proving and illustrating a contractility resident in the fibrous coat.

1. A small living artery, cut across, soon contracts so as to close its canal, and arrest hemorrhage.

2. In an animal bleeding to death, the arteries continue to accommodate themselves to the decreasing quantity of blood, and contract even far beyond the degree to which their simple elasticity would carry them: they relax again after death. Dr. Hales took seventeen quarts of blood from a horse before it died, in whose body only three quarts more were found altogether, and yet the moment before death the tension of the arteries sustained a column of two feet of blood in his experimental tube.

3. The artery of a living animal, exposed by dissection to the air, sometimes contracts in a few minutes to a great degree: and occasionally, in such a case, a single fibre only of the artery contracts, affecting the channel like a thread tied round it. *(See Parry on the pulse.)*

4. When a living artery is tied, the part between the ligature and the nearest branch on the side of the heart gradually contracts, and becomes at last a solid or impervious cord.

5. Fluctuation in the degree of vital action in parts, is often attended with sudden increase or diminution of calibre in the arteries concerned.

Although these facts prove indubitably a contractility in the coats of arteries distinct from their elasticity, still, because the circular fibres do not resemble common muscles in colour or in chemical composition, or in being immediately obedient to the stimuli of electricity, pricking, great heat, &c., their contractility was by many for a long time denied. The dispute, however, was often merely about the words *contractility* and *muscularity*.

The pulse in the arteries, chiefly as regards its almost instantaneous occurrence over the whole system, in all states of arterial dilatation, and its great strength and sharpness in very small and remote branches, points also to the active contractility of the arterial coats.

1. Were the arterial tree in the living body a system of tubes as readily admitting of farther dilatation as in the dead body, the first part or trunk, would affect the motion of the blood beyond it, nearly as the *air-vessel* (see page 296) placed at the commencement of artificial arrangements of water-pipes affects the motion of the water in them;—that is to say, as this converts the sudden and interrupted jets from pumps of *fire-engines*, *town-supplying pipes*, &c. into a uniform stream with scarcely a remnant of shock, so, in the arterial branches, the elasticity would cause a more tranquil flow and a quieter beat than that bounding pulse of life felt in the remote artery of the wrist, as sensibly, in proportion, as near the heart itself.

2. Were the pulse a wave in tubes yielding as readily as the dead arteries in their middle states of dilatation, it would be very distinctly progressive from the heart to the extremities; but it is

felt so instantly over the whole body, as to be compared commonly to a shock of electricity.

3. A pulse may be produced artificially in the arteries of a body recently dead, by filling them with water to the tension of life, and then injecting at intervals, by a syringe, as much water as the heart throws of blood at a pulse: but the beats, although the artery is then distended nearly to the limit of its dilatability, and is therefore rendered rigid, are very different from those of the living pulse. A similar experiment, tried by connecting the artery of a living animal with the corresponding artery of a dead one, has a like result.

4. A tube, greatly elastic, that it might convey a wave of liquid with a velocity approaching to that of the pulse, would require to be so tense from fullness as to be discernible always by the touch, like a hard cylinder or cord; and it would be acting constantly as a spring tending to straighten itself, and therefore, stiffening the parts through which it passed. Now the living arteries, between their pulsations, are almost as soft and compressible as the surrounding flesh, and offer no perceivable opposition to bending, in the various movements of the parts—as in the lips, for instance, or in the fingers; but when a man sits cross-legged, the well-known shaking of the suspended foot, in unison with his pulse, shews the recurring efforts of the artery to straighten itself, during the moments of greater tension.

5. A bulky wave in elastic vessels would have to recoil from the extremities, or to pass through them

as a gush: and the recoil would be particularly observable from the ligature of a tied artery: but examination has not detected such effects in the living body. The tying of an artery *beyond* an aneurismal tumour would almost certainly produce bursting, if it checked a strong wave; yet Mr. Wardrope performed this operation in 1825 with successful issue.

6. The wave would be more interrupted by the bandage in the operation of bleeding, than the living pulse is.

7. The pulse of a paralytic limb often seems more affected than change of size in the artery will account for. The same is true, in an opposite way, of the pulse in an artery leading to an inflamed part.

8. If the abdomen of a living animal be opened, the mesenteric artery, in all its ramifications, is seen stiffened and raised up suddenly with every pulsation, and so instantly all over, that the spreading of newly received blood in a very yielding vessel cannot be the cause.

9. In the interesting experiments of *Bichat*, *Parry*, and others, to ascertain the exact extent of the supposed dilatation and contraction of arteries during a pulse, not the slightest degree of either was discernible, even when sought for with microscopes.

To explain these and other phenomena, then, we must admit either a sudden slight contraction of the arteries throughout the whole body almost simultaneous with the contraction of the heart itself, or such an action of their contractile fibres, as to modify their natural elasticity, and to render them rigid enough, whatever their accidental degree of dilatation may be, for the heart to produce its effects through them almost as it would through tubes of metal. Dr. Young, in a paper published in the Philosophical Transactions for 1809, and characterized by the usual elegance and precision of his writings, has shewn from experiments and calculations, that waves in elastic vessels advance more quickly than most persons imagine; but the spreading of the pulse is yet more rapid than the calculation anticipates. It is evident, that when arteries, in consequence of depletion, are contracted beyond the middle station of their elasticity, their tension and power of quickly conveying the pulse must be dependent altogether on the condition of their contractile fibres.

The careful experiments which could detect no change of size in the arteries during the pulse, while they disproved the ancient belief of a considerable tumefaction or wave passing along, or of a filling and emptying of arteries, as of the heart, might also be supposed to contradict the idea of a general contraction on the contents, but erroneously: for if a man's arterial system, considered as one cavity, be supposed to contain five pounds of blood, (which is probably near the truth), and if the vessels be thought to embrace their contents with force enough to give them all a rounded or cylindrical form, although they remain between the pulses soft and yielding to the pressure of the finger; and if we suppose their coats then to be thrown into sudden and powerful contraction, as if in obedience to an electrical shock; because blood is incompressible, and because just as much enters the arteries with every pulse as escapes from them before the next, their bulk would not sensibly diminish by the strongest conceivable action of their coats, and the only sensible effects of it would be that the soft, yielding, and, in some places, compressed tubes would be suddenly converted into hard or resisting cylinders; and wherever, by any accidental pressure, an artery had been flattened, in regaining its cylindrical form it would strike or pulsate against the compressing body.—Whether such an action as this contributes to produce the arterial pulse will be enquired under the head of *the pulse*, after we have seen how the blood moves in the capillaries and veins.

In any admissible view, then, of arterial action, we find that the arteries can contribute in no other way to the motion of the blood, than as tubes which convey it: their tension, and therefore the force with which the blood is pressed into the capillaries, is derived from the heart alone. Many physiologists have had a confused belief, that the arteries aided actively in propelling the blood, but a very little reflection would have shewn that as they have no vermicular or progressive contraction, like the intestines, they can no more *propel* fluid within them than any rigid or elastic tubes would.—Although they are thus in no degree instrumental in the propulsion of the blood, still, by enlarging or diminishing their calibre, they may much influence the speed of its transmission and its distribution.

The nature of this work does not allow us to record here historically the various errors which even able men have fallen into, in attempting to explain the office of the arteries, but we shall glance at the following.—*Dr. Munro* and *John Hunter*, two of the most able physiologists that have lived, believed that they did almost as much in propelling the blood as the heart itself; and some teachers of the present day also speak largely of their *propulsive action.* We need not repeat the refutation of this opinion. The ingenious *Bichât*, unable to detect either momentary contraction or dilatation in the arteries, thought that the blood was pushed through them by the heart, as a solid rod of metal or wood is advanced instantly in its whole extent, by an impulse at one end. Dr. Parry took nearly the same view of the subject, and illustrated his idea by referring to the experiment of moving a whole line of billiard balls by pushing at the extreme one. Both these authors erred by neglecting the hydrostatical truth, that pressure in a fluid operates equally in all directions, and therefore, that fluid pressed into a tube, tends to dilate the tube, just as powerfully as to drive the fluid before it: and they did not advert to the fact that the stream of blood in the small arteries is nearly uniform. The blood could only advance, as they supposed, by the arteries becoming absolutely rigid, for an instant, through an action of their contractile fibres.

It merits notice here, although not strictly a mehanical fact, that arteries permanently increase or diminish in size when a permanent change takes place in the demand for their service. The arteries of the *gravid uterus*, or of an increasing tumour, grow with the part supplied, while on the contrary, those of a stump left after amputation, soon remarkably diminish. If the chief artery of a limb become obliterated, as after the operation for aneurism, the small collateral anastomosing branches increase in size to do its duty.

It is further remarkable, that when arteries are called upon to carry an increased quantity of blood, they often become tortuous or serpentine, as well as larger; and arteries leading to parts whose actions are naturally intermitting or fluctuating, have generally the tortuous form. Instances are, the arteries leading to rapidly growing tumours, or to varicose aneurisms, and the arteries of the uterus and testes. This bending of arteries and the very curious division into many branches which again reunite, found in the arteries leading to the brain in some animals, do not seem intended to slacken the rapidity of the sanguineous current, but to give the artery a greater control over the supply.

Passage of the blood through the capillaries.

We have seen that the heart keeps up a tension or pressure in the arteries, of about four pounds on the square inch of their surface; and with this force, therefore, is propelling the blood into the capillaries. If these last were passive tubes, constantly open, such force would be sufficient to press the blood through them with a certain uniform velocity: but they are vessels of great and varying activity: it is among them that the nutrition of the different textures of the body takes place, as of *muscle*, *bone*, *membrane*, &c., and that all the secretions are performed, as of *bile*, *gastric juice* or *saliva*, &c.; and to perform such varied and often fluctuating offices, they require to be able to control, in all ways, the motion of the blood through them. The capillaries of the cheek, under the influence of shame, dilate instantly, and admit more blood, producing what is called a *blush;* —under the influence of anger or fear, they suddenly empty themselves, and the countenance becomes pallid—tears or saliva gush in a moment, and in a moment again will stop—if a person having inflammation in one hand be blooded from corresponding veins in both arms at the same time, twice or thrice as much blood will flow from the diseased side as from the other. Similar changes occur in many other instances. Now the only mechanical action of vessels, capable of causing these phenomena, is that of contractile or muscular coats; and with reference to such action it merits notice, that arterial branches have always more of the fibrous or contractile coat in proportion as they are smaller.

A muscular capillary tube strong enough to shut itself in spite of the action of the heart, is also strong enough to exert an equal force in propelling the blood to the heart again through the veins. If we suppose the first circular fibre of the tube to close itself completely, it would, of course, be exerting the same repellent force on both sides, or as regarded both the artery and vein. If then the series of ring fibres forming the tube were to contract successively towards the vein, as the fibres of the intestinal canal contract in propelling the food, it is evident that all the blood in the capillary would thereby be pressed into the vein towards the heart: and if the capillary then relaxed on the side of the artery, so as to admit more blood, and again contracted towards the vein as before, it might produce a forward motion of the blood in the vein, independently of the heart. We, of course, state this merely as a possibility, for the intimate nature of capillary action is not visible, and is not positively ascertained.

It is capillary action which absorbs and moves the fluids of the classes of animals which have no heart. It must also be the power which moves the blood in warm-blooded monsters formed without hearts. There are cases of apparent death among human beings where the heart remains inactive for days, and yet a degree of circulation sufficient to preserve life is carried on by the capillaries. In further illustration of capillary action, we have the absorption of nourishment from the alimentary canal by the lacteals; and perhaps the circulation of the blood in the liver of animals. In this last, the blood collected by veins from the abdominal viscera, instead of going directly to the heart, is distributed through the liver by the branches of the *vena portæ;* and from these it is again collected by ordinary veins, and carried to the heart: it thus moves through two sets of capillaries in passing from the arteries to the heart again.

The action of the capillaries is the cause of that singular phenomenon which prevented the ancients from discovering the circulation of the blood, *viz.* the empty state of the arteries after death. The muscular parts of an animal retain their life, or power of contracting, for a considerable time after respiration has ceased, as is seen in the recovery of persons apparently drowned or suffocated; in the leaping of a heart taken from an animal just killed; in the actions resembling life which can be produced in a body recently dead by the agency of galvanism; and still more aptly for our purpose, in the total disappearance of a local inflammation after the death of the patient:—inflammation involves a gorging or over-distension of the capillaries, and when the heart has ceased to press blood into them, the contractile force remaining in them, even under disease and in a dead animal, is sufficient to squeeze the blood out of them, and often to remove all trace of the malady which has been fatal.—In ordinary cases, the capillaries throughout the body remain alive and active for some time after breathing has ceased, and they work like innumerable little pumps, emptying the arteries into the veins. As the red blood is their proper sustenance as well as stimulus, they work as long as there is any of it coming from the arteries behind them: the capillaries of the lungs, however, soon cease to act, because, after breathing has ceased, they are filled with black blood, and are moreover compressed by the collapse of the chest, and all the blood accumulates behind them. The capillaries may fill themselves from the arteries, either by a strong elasticity opening them with what is called a suction power, or by an absorbent power dependant on life, like that of the lacteals and of the absorbents all over the body, and perhaps, of the vessels in the roots of vegetables. When death is produced by lightning, or by the poisons which destroy muscular irritability, and therefore capillary activity, the arteries are found to contain blood like the veins. In a living body, if an artery be tied, the part beyond the ligature is soon emptied into the veins, and becomes flat.—The experiment has been made even upon the aorta itself.

The empty state of the arteries after death is still ascribed, by some teachers, to the momentum with which the blood is supposed to be thrown out from the heart in its last contraction—sufficient, according to them, to squirt it fairly through the most distant capillaries: a doctrine exemplifying the carelessness with which able men sometimes receive and repeat opinons to which their attention has never been fully awakened. The effect supposed here would not follow, even if the dying action of the heart were the strongest possible; while, in reality, in most cases, it is so feeble, that the pulse for some time ceases to be perceptible at the extremities, and the diminished circulation lets them become cold.—Other physiologists teach that an artery is capable of contracting directly upon its contents, so as to expel even the last drop; but large arteries, when emptying, do not contract *roundly* like an intestine, they become *flat* like elastic tubes of leather sucked empty, and no contractile action of the vessel itself could bring its sides together in such a manner. If arteries emptied themselves by their own action, the pulmonary artery should be more certainly empty than the aorta, because it is shorter: yet it is always full; the chief reason being, as already stated, that the pulmonary capillaries cease to act after respiration has ceased, the blood in them being the venous or dark blood, and therefore not stimulant.

Passage of blood through the veins.

The veins have much thinner coats than the arteries; and if taken altogether, they have much greater capacity, because they exist, in many situations, as double sets; an exterior and an interior set; they have also very frequent inosculations or communications with each other throughout their whole course.

The simple weight of the column of blood in any descending artery is just sufficient to raise the blood through open capillaries to an equal height in the corresponding vein, according to the hydrostatical law, that fluids attain the same level in all communicating vessels. And in addition to this influence of gravity, the blood is farther pressed into the arteries, and from them therefore towards the veins, with a force from the heart, as stated above, of about four pounds to the square inch, or, in other words, as if there were a column of blood eight feet higher than the heart urging the current. Now it might be expected from the law of equal diffusion of pressure in fluids, that these causes would soon produce a tension in the veins as great as in the arteries; but this does not happen, because the blood has a ready escape from the veins through the right ventricle of the heart: so that, under ordinary circumstances, there never can be greater tension in them than just enough to lift the blood to the heart and to overcome the friction. Accordingly, Dr. Hales' experiments, already alluded to, proved that, under ordinary circumstances, a tube connected with any vein so as to receive its blood, became filled with blood to a height only of about six inches above the level of the heart. He generally cut the vein completely across, and inserted the tube into the portion leading from the capillaries: and he would thus have discovered the whole power with which the blood is pushed along the veins from the capillaries, but because the free lateral communications of veins with each other reduces the tension even in an obstructed branch, to that existing in the system generally. When from agitation of the animal, or straining exertion, the passage of the blood into the heart was impeded, the veins became so tense, that a tube inserted into the returning jugular had blood running over, at a height of three feet above the heart.

If the blood had no escape from the veins, the only cause which could prevent the venous tension from becoming as great as the arterial, would be obstruction in the capillaries: but the following facts and considerations prove that these vessels, which in the dead body readily allow the passage of injections, in the living body also freely allow the passage of blood. 1st. Majendie laid bare the chief artery and vein of a living limb, and lifted them at the part, so that he could make a tight bandage round the limb without including them; it was then found that the flux of blood from a puncture made below a ligature on the vein, was rapid or slow, according as the heart was allowed to produce a greater or less degree of tension in the artery: this tension was regulated by compressing the artery between the fingers. 2d. After a similar preparation of the parts, it is found, that the blood will ascend in a tube from the obstructed vein as high as from the artery. 3d. In the common operation of bleeding, when the vein is first punctured, the blood jets from it as from an artery. 4th. The microscope discovers the uniform forward motion of the blood in the capillaries, as if it were obeying the steady pressure of the arterial tension. 5th. Disturbed action of the heart, obstructing the passage of the blood through it, very soon causes a tumefaction of all the veins leading to it. This becomes very visible about the neck and head, and in the liver produces swelling and acute pain. 6th. Dr. Young, from experiments made by him, and reported in the Philosophical Transactions for 1809, concluded, that perfectly open capillaries, of the size existing in the living body, should just retard a flow of blood urged by the usual arterial tension, in the degree which really occurs:—and open vessels, however small, although transmitting blood slowly, still if its escape from the veins were arrested, would transmit the arterial tension without diminution. 7th. The action of the capillaries, which after death empties the arteries into the veins, proves that, under certain circumstances, the venous tension may become even greater than the arterial.—These facts, then, prove incontestably that the blood is pressed into the veins from the arteries and capillaries with force sufficient to lift it, not only to the heart again, but many feet farther, *viz.* as far as it would ascend in a tube rising from the tense arteries themselves. So little, however, has this important truth been understood, that in elementary works of authority lately published, the state of the veins is treated of as a very obscure subject; and some authors, in their anxiety to explain it, have assigned causes for the venous current, which, as will appear hereafter, are even positive absurdities in physics. The difficulty in the question seems to have arisen from the disparity found between the tension in the arteries and in the veins; and from the want of reflecting, that owing to the hole or outlet from the veins through the heart, they must in general, like any other open tubes, exhibit only a tension or pressure proportioned to the height of liquid in them above the part examined, with a little addition for the resistance of friction to the moving liquid.

The ingenious Bichât, with a carelessness of facts unusual in him, oddly persuaded himself that the influence of the heart ceased entirely at the capillaries, and that the blood was returned through the veins by the action of the capillaries alone. How could he avoid the single reflection, that, if the purpose of the arteries had been merely to convey the blood *to* the capillaries, and not *through* them, the extraordinary strength of their coats, and the great power of the heart to fill them, and keep up the tension described, would have been quite superfluous?—and he knew that nature does nothing in vain. This remark would apply strikingly to the pulmonary artery, of which no branch exceeds a few inches in length.

The uniform current of blood along the veins, which the combined influence of the heart and capillaries is calculated to produce, and which is rendered apparent in the operation of bleeding, suffers a considerable disturbance in the neighbourhood of the heart from three causes. 1st. As there is no valve between the veins and the auricle of the heart, each contraction of the auricle tends to throw the blood back into the veins, as well as forward into the ventricle. 2d. When the chest is expanded by inspiration, it is more roomy than during the collapse of expiration, and the blood then enters it more readily. 3d. While the chest is *inhaling* or *drawing in* air; that is to say, expanding so as to diminish the atmospheric pressure in it (see *Pneumatics*), it is by the same action favouring the entrance of blood by the veins towards the heart placed in it; and, on the contrary, while it is *exhaling* or *throwing out* air, it is, with equal force, resisting the entrance

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of blood, and slackening, or even causing recoil of the inward current. This favouring or resisting force, as will be hereafter shewn, is such as to lift or support a column of blood of about half an inch in height. The entrance of blood into the chest therefore fluctuates by reason of the respiration, as the entrance of a river stream into the sea, fluctuates by reason of the ebbing and flowing of the tide. An eye watching the jugular vein, under favourable circumstances, sees it tense or slack in accordance with the opening and shutting of the chest, and a finger placed upon it may often detect the *venous pulse* produced by the contractions of the auricle.

It still remains to be ascertained whether veins have any active contractile power in themselves, such as partially to empty a lower portion into a higher beyond an adjoining valve. The valve then bearing the pressure, blood would more easily be raised from below into the portion so relieved, and the action, without being equal to the office of completely emptying any portion of a vein, would still have the effect of dividing a long heavy column into a number of short columns of comparatively little resistance. It is certain that the valves in the veins, by preventing the return of blood which has once passed towards the heart, must affect its flow during bodily exercise; for every time that pressure is made on a vein by a swelling muscle or otherwise, the blood in the part must be forced forward, and cannot return. The veins surrounded by muscles are thinner and weaker than those supported only by the skin. The external veins of the legs are almost as strong as arteries: but any vein in the living body made to communicate directly with an artery, as in the case of *varicose aneurism*, soon swells to bursting. Veins possess power, to a great extent, of adapting themselves to the varying quantity of blood.

Some recent authors, as stated above, either not being aware of the facts which prove that the blood is every where pressed into the veins from the capillaries, with force much more than sufficient to raise it to the heart again; or being unable, from their little familiarity with physics, to draw exact conclusions from the facts, or to avoid errors in their own hypotheses, have promulgated the opinion that the progression of the blood in the veins is greatly owing to a suction power in the heart or chest; that is to say, to the atmospheric pressure remaining constant on the body generally, while it is occasionally lessened about the heart;—a circumstance, of which the whole effect, as stated above, is merely a slight disturbance of the uniformity of the venous current near the chest. Now such a doctrine could not be proposed or entertained for a moment by a person understanding the principle of a common household pump; and that it has been published and tolerated by able men in the present time, will remain a proof to posterity of the deficiency, as regards fundamental science or natural philosophy, which now exists in the ordinary medical education. Much ingenuity has been wasted upon it, particularly by Drs. Carson and Barry, the latter of whom, after laborious investigations, by experiment on living animals, has even attempted to build upon it a superstructure of medical theory and practice. The fault, however, may be less in the parties who have been pursuing what appeared to them an important object, than in the system of education which left them exposed to such errors. Dr. Barry need not blush to have proposed an explanation, in which members of the French Institute, sitting to judge it, were not prepared clearly to point out the fallacy. To say that the influence of the heart or chest is the power which draws the blood to the heart from the general system, is just as if one asserted that the ocean tide at the mouth of a river is the power which collects the tributary streams in the interior country.

We shall enter into a little detail on this subject, because the discussion will elucidate some minor points connected with the circulation.

Presuming, then, that the reader perfectly understands the theory of pumps, and therefore of atmospheric pressure, as explained under *pneumatics*, he will readily understand the two following propositions, either of which proves it to be a physical impossibility, that a sucking action of the heart or chest can be a cause of the blood's motion along the veins. 1st. The veins are pliant tubes free to collapse, and no pump can lift liquid through such. 2d. The *suction power* of the chest in ordinary respiration is too weak to lift liquid a distance of even one inch through tubes of any kind.

A practical illustration of the first proposition is afforded by putting the point of a syringe, capable of making a complete vacuum, if desired, into a piece of gut, or eel-skin, or vein filled with water, and then trying to pump up the water. The result will be, that the fluid close to the mouth of the syringe will enter it, and the sides of the pliant tube will then collapse as a valve against the syringe, making an end of the experiment. In exact proportion to the rigidity of the tube would be the distance to which the influence of the syringe would extend in it: if it required, for instance, half an ounce of pressure on the square inch of its surface to make it collapse, then the pump would draw up one inch of water, and so for other proportions. If during the action of the syringe, the tube were allowed to open at the bottom into a vessel of water, instead of the syringe then drawing any more water from the vessel into the tube, the original contents of the tube would straightway be discharged downwards into the vessel: and the result would be the same even if there were a thousand tributary streams pouring into the tube, unless they entered with force enough to rise up to the syringe.

The explanation of all these facts is found in the pressure of the atmosphere (see from page 308 to page 320), seeking entrance every where at the surface of the earth, with a force of fifteen pounds per square inch, and overcoming any opposing force less than this,—sufficient, therefore, to push a column of water thirty-four feet high through a rigid tube into the vacuum of a pump, but causing the sides of the tube to collapse, unless able to sustain at any given part, a compressing force equal to the weight of water in the tube below.

Some bad reasoners on this subject have believed, that if a suction power exist equal to one inch column of liquid, any column, however long, must follow the first inch when acted on by the power in question; for, say they, the atmospheric pressure preventing a vacuum will prevent separation of the liquid. Now this reasoning is altogether inapplicable to pliant tubes, because the ready collapse of their sides will both allow the separation, and prevent the vacuum; and with respect to rigid tubes, it is equivalent to asserting that a force just capable of lifting one link of a chain, must therefore be able to lift any number of connected links. Water in a rigid tube, to which air has no admittance, may be considered as a chain, for it is held together by a force of fifteen pounds per inch pressing inwards at the two ends: and any force less than this, cannot therefore lift one portion of it away from another, and therefore cannot draw out a drop but by lifting the whole. A man cannot suck water from a full rigid tube which is closed at the bottom, and if the bottom be open, and he has not power to support the whole contained fluid, it will sink from his tantalized lips to stand at an elevation marking his suction power.

To illustrate the second proposition respecting the trifling suction power really residing in the chest, we shall state that a person of ordinary strength, using the power of the chest only, and not of the mouth separately, (which is a smaller and much more powerful pump than the chest), cannot through a rigid tube suck water from more than about two feet below: and the opposite action of blowing outwards has nearly the same limit as is found by dipping the end of a tube two feet into water, and then trying to blow through it. Now as water rises more than thirty feet towards a perfect vacuum, such as that of a good pump, the facts mentioned prove that the diminished pressure in the chest, as an approach to a vacuum, is never more than *one-fifteenth* of the whole, and that the increased pressure during straining, is in a corresponding degree. But in ordinary breathing, instead of differences corresponding to a liquid column of two feet or a *fifteenth*, the increase and diminution of air-density, in the chest, is measured by a column of less than one inch, or about a *five-hundreth*. This is easily shewn on breathing through the nose, and holding one end of a glass tube in the mouth while the other end is immersed in water, by noting how much the water in the tube rises above the surrounding level during *inspiration*, and sinks below it during *expiration*. The mouth during this experiment may be considered as part of the general cavity of the chest, to and from which air is passing by the narrow openings of the nostrils. In tranquil breathing, with both nostrils open, the fluctuation in the tube is less than half an inch each way; with one nostril closed, and the other a little compressed, it may amount to a whole inch; and with hurried or convulsive breathing, like that of an animal in terror or in pain, it may exceed twelve inches. Although the measures so obtained from the mouth are somewhat too small for the changes in the chest itself, because the chest is more remote from the opening by which the external air enters, the difference is very trifling, as is proved during such experiments by stopping the nostrils altogether, and continuing the same respiratory efforts; and also by the agreement of the results with strict calculation founded on the inertia and velocity of the air respired:—a calculation similar to that required in adjusting the index to the machine for measuring water-currents, described at page 405. In common healthy breathing, with the mouth open, the fluctuation of pressure in the chest is measured by less than half an inch motion each way of the liquid column. Dr. Barry, not aware that this point could be so easily determined by the bloodless experiment described by the author above, or even by a simple calculation, has sought the solution by numerous trials on living animals, into some part of whose chest he forced a tube; but even if farther experiments had been at all necessary, these of Dr. B. could not have decided the question. 1st. Because the breathing became violent or unnatural, from the pain and agitation of the animals; and, 2d. Because the experimental tube often or always became a syphon; and Dr. B. not adverting to this fact, has not recorded the difference of level in the liquid at the two ends. That the external level was for the most part higher than the internal, is proved by his having noticed almost solely the *inhaling* action of the chest, although the *exhaling* is generally an equal, and often a more powerful effort.

Calling an inch column of blood, then, the measure of the greatest sugescent and repellent powers of the chest during ordinary respiration, we see that the force which really sends the blood from below to the heart, may have to lift a column one inch shorter during *inspiration*, and one inch longer during *expiration*.—And this is the full and true measure and nature of the influence of the respiration on the blood's return to the heart by the veins. To say that the atmospheric pressure, modified by respiration, is the great power which moves the venous blood, is as if we said, that a boy standing near the ponderous fly-wheel of a steam-engine, and giving it his Lilliputian thrust, alternately backward and forward, were the prime moving force of the machinery.

Were it necessary to give proofs, to persons unable to follow the above argument, that a suction power in the heart or chest is not the force which draws the blood from the extreme veins, the reference is ready to many notorious facts quite incompatible with that supposition; such, for instance, as some recorded at page 502, and others.—A vein tied, fills tensely below the ligature—a vein cut across bleeds from its distant orifice, and will fill a lofty tube connected with it—the circulation is perfect in the *fœtus in utero* which breathes not—and it goes on in persons holding their breath, and in divers, &c. &c.

After the explanations now given, it is almost superfluous to remark that *absorption* in animals cannot depend on atmospheric pressure, and that the effect of cupping-glasses applied to extract blood, or to prevent the absorption of poison in wounds, in no way depends upon the fluctuating density of the air in the chest. Dr. Barry's reasonings upon these subjects involve the same fallacy as his reasonings on the venous current. With respect to absorption, they neglect the fact of fluids having weight; and with respect to cupping-glasses, of which the true action is explained at page 325, they are equivalent to asserting that the action of pumps drawing water from a river among the hills is influenced by tides, or pumps operating at its mouth in the sea.

If the fluids in animal vessels had no weight, it is true, that in absorption, an external atmospheric pressure of fifteen pounds per inch might force new matter into a receiving orifice at the instant during inspiration when the opposing pressure in the chest at the other ends of the vessels were half an ounce per inch less,—there would be no physical absurdity in supposing this, although there are physiological facts that disprove it—but when we reflect, that in all vessels under the level of the heart, the weight of the fluids causes an additional outward pressure of about half an ounce troy for every perpendicular inch of fluid column, making an excess of outward pressure at the toes, even at the most favourable time for absorption, of about two pounds per inch, we see that absorption must be a strong *action of* *life*, able to overcome a great excess of mechanical resistance, instead of a passive phenomenon obeying an excess of mechanical force. If a mere balance of pressures acted at the orifices, as Dr. B. supposes, the blood and other fluids would be constantly oozing from all orifices below the heart, as blood really does from an artificial opening, and with force that would fill a tube reaching as high as the heart. It would be good news for proprietors of mines and others having to raise water, if by taking off an ounce or two per inch of the atmospheric pressure at the top of a full pipe, the constant pressure elsewhere would then force in water at openings below, and cause an upward current:—but in truth, to make the atmosphere efficient below, powerful steam-engines or other means must be used above to take off a pressure of half an ounce per square inch for every inch in height which the water has to rise.

Another erroneous view of atmospheric pressure akin to that which we have been considering, is expressed in the following reasoning on the progress of blood in the veins.—The atmosphere presses 15 lbs. per square inch on all things; the blood in a vein, therefore, with 20 inches of surface, is pressed, through the flesh, with a force of 20 times 15, or 300 lbs., while a cross section of the vein near the heart might measure less than one inch. The blood is therefore always running towards the heart from a powerful excess of atmospheric pressure.—The law of fluid pressure, explained at page 229, solves this paradox. The same reasoning would prove that an eel-skin filled with water and suspended by its lip, when exposed to the pressure of the atmosphere, should quickly run over, and be emptied; and nearly the same would prove that a long sharp wedge thrown into water should seem always to be running away from its point; and that a ship formed like the wedge should make quick speed across the sea without either oar or sail.

A knowledge of the facts detailed under the three heads of *arteries*, *capillaries*, and *veins*, prepares for the discussion of the following subjects.

The force of the heart.

The arterial tension of four pounds to the square inch, marked by its supporting a column of blood eight feet high, is produced by the action of the heart; but as the heart, while injecting the blood against this resistance, has moreover to overcome the *inertia* both of the quantity injected, and of the mass in the great artery first moved by the injection, and the *elasticity* of the vessel yielding to momentary increase of pressure, the heart acts probably with a force of six pounds on the inch. Now as the left ventricle of the human heart, when distended, has about ten square inches of internal surface, the whole force exerted by it may be about sixty pounds. It is remarkable that, with this easy means of solving the question, the correct and elegant Majendie in his recent elements of physiology, should speak of it as undetermined; and as the best approximation, should cite a calculation from the obscure circumstance of a loaded foot shaking in unison with the pulse, when suspended in the cross-legged sitting attitude.

The velocity of the circulating blood

Has been much over-rated. 1st. By assuming that the ventricles of the heart are filled and emptied at each pulsation. Now this is disproved on exposing the heart of a living body; and also by the valves between the auricles and ventricles not closing so perfectly as quite to prevent regurgitation. 2d. By supposing the issue of blood from a wounded artery or vein to be the measure of the usual velocity. Now it would be as reasonable to suppose the issue of water from any pipe connected with a reservoir to be the measure of a continued current in the pipe, although an equal issue would occur whether the water in the pipe were usually at rest or in motion. 3d. By supposing the *frequency* of the pulse to be a measure. Now we know that in diseases of debility, and in animals bleeding to death, the pulse usually becomes frequent as it becomes more feeble, and as there is less blood moving. 4th, and lastly. By supposing the *strength* of the pulse to be the measure. Now we find that the pulse in an artery just tied, and where consequently there is no current at all, is little weaker than in an open artery.—The common fact of a person's feet remaining stone-cold for hours, although the pulse in the arteries leading to them be nearly as usual, is a proof that exceedingly little blood is passing through the capillaries at the time, and that the pulse is therefore no measure of its speed.

The ventricles of the heart appear, under common circumstances, to throw out about an ounce and a half of blood at every contraction—or about seven pounds per minute. Now if the body contain about twenty pounds altogether, as is probable, the whole would circulate twenty times in an hour. This would give an average velocity of about eight inches per second in the aorta, becoming gradually less in the smaller arteries, because whenever an arterial channel subdivides, the branches taken together have considerably greater area than the trunk from which they arise, and thus the collective channel goes on increasing in magnitude as the divisions are more numerous, and the current diminishes in a corresponding proportion;—just as the speed of a river stream is always less in the parts which are deeper and broader. The velocity in the extreme capillaries is often less than one inch per minute. In the veins the blood must move as much more slowly, than in corresponding arteries, as the veins are larger than the arteries.

The pulse.

The opinion which the ancients held, that the arteries contained *vital spirits* or *air* and not *blood*, rendered the pulse, to them, a very mysterious phenomenon; and many curious hypotheses were framed to explain it. These it would now be unprofitable to detail. Even Harvey's grand discovery of the circulation, however, has not rendered the subject so simple as might have been anticipated. The following opinions exist, or have lately existed, with respect to the pulse.

1st. The great majority of physiologists have believed that a tumefaction is produced in the aorta by each jet of blood from the heart, and spreads afterwards as a wave into all the arterial branches. 2d. Many have supposed a contractile action of the arteries themselves, corresponding to that of the heart. 3d. Bichat, being unable by any means to detect the slightest change of diameter in the arteries during pulsation, but perceiving that in many situations they were somewhat lengthened, causing straight portions to bend a little, and curved portions to bend still more, held that this locomotion of the artery was the cause. 4th. Others have supposed the impulse of the heart's contraction to be conveyed through the fluid blood, somewhat like sound, or like a blow struck on one end of a log of wood, which is felt distinctly by a hand applied to the other, although there be no visible locomotion. 5th. Dr. Young, in the paper in the Philosophical Transactions already alluded to, has explained that a sudden rush forward of the blood in the artery, such as would be produced without any increase of size, by injection at one end of a rigid tube, would be felt by a finger applied, quite as distinctly as a tumefaction, and he deems this occurrence a chief cause of the pulse. Dr. Parry, in his work on the pulse, points to it as the cause almost exclusively.

Now the truth is, that the pulse in the living body does not depend upon any one of the particulars noticed, but has all of them as elements, and its fluctuations and varieties depend upon the proportions in which the elements are combined. We shall review them again to prove this truth.

1st. A tumefaction or wave *must* spread from the heart to the extremities at each jet of blood thrown into the aorta; for it is evident, that if blood be at all pushed into the arterial system, it either must dilate it, or cause an equal quantity to be expelled at the same instant from the distant extremities: now as the passage of blood through the capillaries appears perfectly uniform, there must be an intermediate dilatation. Dr. Parry and others, should not have denied this dilatation because they could not see it: for even if its advancing front were more considerable than it is, from passing with the velocity almost of a shock of electricity, it could no more be visible than a cannon ball crossing before the face.

2d. Contraction of the arteries themselves certainly does not take place in the manner, and to the extent, supposed by those who have spoken of it as a means which might be a substitute for the action of the heart itself in propelling the blood; but, as shewn at page 489, the rigidity of tube which causes the pulse to be transmitted so quickly in all degrees of arterial dilatation, can depend on nothing else but a contraction. There are some reasons for doubting whether this rigidity may not increase at the moment of the pulse.

3d. Unless the arterial tubes were absolutely inelastic, which they are far from being, they *must* be lengthened a little by a sudden injection of blood, and therefore, at all the curvatures particularly, there *must* be a degree of locomotion, often sensible to a finger applied.

4th. That a tangible shock is conveyed through a fluid without any apparent accumulation of it or change of velocity, and much in the manner of sound, is proved by the facts, that we may discover the working of a water-pump at very great distances through the iron pipes leading from it, and even through elastic leather pipes, as those of a common fire-engine, from which the water spouts in a uniform stream. The pulse in a tied artery, in which there is no current or rushing wave, is chiefly of this nature and from the locomotion of the artery.

5th. That any additional quantity of fluid injected into elastic vessels already full must spread all over with a forward rush, affecting the finger of an examiner as described above, is also most certain. The heart, however, often beats without discharging much of its blood, and in many arteries, from inaction of the capillaries, or pressure, the blood for a time makes little or no progress, and yet the pulse remains very distinct: it must be produced in such cases independently of the forward rush. An animal intestine prepared and filled with water or air and laid upon a table, or a full vein in the living body, carries a rapid and distinct pulse to a great distance when gently tapped by the finger. The cause of the sensation there cannot be the simple forward *rush* without tumefaction, described by Dr. Young and Dr. Parry.

In whatever proportions these causes combine to form the pulse, its force must be proportioned to the size of the artery. Hence as an artery leading to an inflamed part becomes of greater calibre, its pulse also becomes stronger.

It is a remark respecting the pulse, appearing to the author worthy of deep consideration, that if the purpose of the heart and arteries were merely the propulsion and conveyance of the blood, their structure and action would form most signal deviations from the ascertained rules of propriety in mechanics. In machines of human contrivance, it is one of the most important maxims to avoid all shocks, or jerking irregular motions; and in former parts of this work, we have described fly-wheels, air-vessels, springs, &c. as means of obtaining or maintaining uniformity, and of preventing the tearing and straining of parts which would else happen. In the human body, also, we have had to describe the beautiful elasticity of the spine, of the arch of the foot, of the cartilages of joints, &c. answering the same ends: and to remark that, in other cavities alternately filled and emptied like the heart, as the stomach, bladder, uterus, &c., there is smooth and gradual action. The heart alone is the rugged anomaly which, from before birth until the dying moment, throbs without cessation, and sends the bounding pulse of life to every part: and moreover, instead of being secured and tied down to its place, it is suspended to the extremity of the aorta, as a weight at the end of an elastic rod or plank; and every time that it fills the aorta by its contraction, a sudden consequent tendency of this to become straighter throws it with violence against the ribs, in the place where the hand applied feels it so distinctly beating.

One reason probably of the pulsation of the heart, is that the *agitation* and *churning* which the blood suffers in passing through it, may keep in complete mixture all the heterogeneous parts, which so readily separate when left to repose: but this cannot be the only one. The phenomenon seems to have relation to some important law of life still hidden from us. The stimulus of the blood has been assigned as the cause of the heart's contraction: but this seems incorrect, when we reflect that the heart will beat after removal from the body, and when it contains only air; and that during life it beats with extraordinary regularity, whether the state of the circulation allow it to empty itself at each beat or not. We cannot contemplate this subject and not perceive a strong analogy between the action of the heart and some electrical phenomena in which there are successive accumulations and exhaustions of power; and, recollecting the important relations which late researches have shewn between electricity and certain actions of life, the inquiry becomes more interesting:—galvanism can excite the muscles to their usual actions—it affects the secretions and the digestive function, and the breathing in asthma—strong animal passion seems to produce electrical excitement; and certain animals have the faculty of stunning their enemies by an electrical discharge. The pulse, then, in its sudden, strong and regular recurrence, may be a kindred phenomena. In this view, there would be less difficulty in supposing a momentary slight contraction of the whole arterial system, such as the sudden stiffening and rising of the mesenteric arterial tree so readily suggests ;—but if there be such, it is still dependent on, and proportioned to, the action of the heart ; it occurs only with that of the heart ; it indicates any disturbance of the heart's action ; and at death, it ceases in the remote extremities first.

The preceding considerations exhibit the pulse as a complex subject, and one on which professional opinions are not yet settled. By shewing its close relation to the powers of life, they also prove it to be an object of high importance to the medical practitioner—a truth, indeed, which has scarcely been questioned but by persons singularly deficient in the power of tactile discernment, or utterly uninformed. Still, because no simple and good analysis of the pulse, and detail of its relation to morbid states, has yet appeared, the skill acquired with respect to it by individual practitioners is very various, and in a great measure accidental. Some try the pulse merely for form's sake, because patients expect it, and many examine it only to count its frequency ; but others read in it, with great confidence, much of the history and probabilities of the disorder, and hence decide on the treatment. Few who have attended to the subject at all, can confound the pulses of certain diseases, such as acute rheumatism, gastric inflammation, the fits of ague, &c. The author remembers to have conversed with a Chinese practitioner who had only the scanty medical information of his countrymen, but who judged by the pulse in a way to surprise.

The changing circumstances in the state of the circulatory system, connected with health and disease, and discoverable by a finger watching the pulse, are chiefly the following; and the epithets added in italics, are those which best indicate the sensations perceived. The artery at the wrist is that generally chosen for examination, because it is only covered by skin, and has nothing between it and the bone below.

1st. The number of the contractions of the heart in a given time, and the regularity of their recurrence.—Pulse, *frequent*, *slow*, *intermittent*, *equal*, *regular*, *of varying force*.

2d. The degree of the heart's contraction, or the quantity of blood ejected at each time—and the state of the capillaries as to the quantity of blood passing through them, which, of course, must correspond.—Pulse, *full*, *long*, *labouring*, *bounding*, *feeble*.

3d. The force of the heart's action, with the correspondent arterial tension or rigidity.—Pulse, *hard*, *sharp*, *strong*, *wiry*, *weak*, *soft*, *yielding*.

4th. The suddenness of the individual contractions of the heart, and the rigidity of the vessels in conveying the shock.—Pulse, *quick*, *tardy*.

5th. The size of the artery for the time, whether larger or smaller than usual.—Pulse, *full*, *large*, *strong*, *small*, *weak*.

Superficial as is this sketch, it may shew that a good treatise on the subject of the pulse, as connected with pathology, is yet a desideratum in medicine. The sort of empirical, but yet useful tact which many acquire, should not satisfy the reasoning physician; and to judge intelligently, the mind must have present to it all the constituents of the pulse, and all the important circumstances so related to it, that it may indicate them. The laboured treatises of *Solano*, *Bordeu*, *Boerhave*, &c. may treat of what were clear ideas to them, but by not referring to the physical causes of many varieties, they become obscure to others, and many of the divisions and denominations appear altogether fanciful. Dr. Young's excellent paper in the Philosophical Transactions details important facts, but it was not the intention of it to point out all the pathological relations. Dr. Y., guided by physical principles, asserted a progressive motion of the pulse, while other authors were holding it to be quite simultaneous over the whole system; but he seems to have doubted whether the progress could be clearly detected.—Now careful examination may perceive the succession of beats at the four stations: 1st. of the heart; 2d. in the lip; 3d. at the wrist; 4th. at the ancle. As the interval of time, however, even between the extremes, is only a small part of a second, practice is required to make the experiment satisfactorily.

Dr. Parry's treatise on the pulse, which is the last one of note, among many excellencies, errs in attributing the phenomenon to one cause too exclusively; in denying arterial dilatation because it was not discovered by his mode of searching for it, and in supposing that a liquid column in an elastic tube can be made to advance like a solid rod, or a straight line of billiard balls. It signally confirms our remark of the neglect of mechanical philosophy by medical men, to find it stated in works of authority, published at the present day, that the arterial pulse may be either more frequent or less so than the beatings of the heart. *Dr. Good (study of medicine)* says, that there may be various frequency of pulse in various parts of the body at the same time. *Richerand (physiologie)* says, the pulse is more frequent in the artery leading to a whitlow than elsewhere: and many practitioners share these notions. What a satire on the medical profession is this disagreement, on a point which to common observers seems above all others to attract the notice of the attendant on the sick!

Having now explained the circulation of the blood in general, we proceed to consider some cases where mechanical circumstances modify it.

Circulation in the head.

The head may be considered as an air-tight vessel or cavity of bone, containing chiefly brain and blood, and of which the openings are in communication with the blood-vessels leading to and from the heart. The atmospheric pressure, therefore, always keeps the head full, as it keeps the top of a syphon full; and because the substance of the brain does not sensibly change its bulk by any ordinary degree of pressure, there must always be the same quantity of blood in the head, how much soever the quantity may vary in the body generally. Regard to this important truth, made intelligible by the discovery of the true nature of atmospheric pressure, enables us to explain many hitherto obscure facts, both in health and in disease.

If from any cause the arteries in the head become too full of blood, in the same proportion the veins must become too empty; or, if the veins be too full, the arteries must be too empty; and in either case the circulation in the head will be in a corresponding degree impeded, because when any confined channel is narrowed or diminished in one part, the current throughout the whole is slackened. Now as insensibility supervenes when the supply of fresh blood to the brain is interrupted, and death follows if the interruption continue long, it seems evident that in many of the cases of apoplexy, where, on inspection, there is found nothing but a fulness of the arterial or of the venous system of the head, death has happened merely because the circulation was arrested in this way. In other parts of the body not circumstanced like the brain, such unequal distribution of blood happens with perfect impunity to the individual.

Simple increase of pressure produced by the blood on the brain, provided the proper balance exist between the quantity in veins and arteries, has no injurious effect. This is proved by the descent of a person in the diving-bell, where at thirty-four feet under the surface of the water the body is bearing an additional pressure of fifteen pounds on the square inch (see page 297), which affects the brain through the blood-vessels, just as much as any other part.—On the other hand, when a man climbs a mountain, or ascends in a balloon, the brain is less pressed than usual; but the proper balance of artery and vein being maintained, no inconvenience is felt from this cause. The inhabitants of some of the vallies among the Andes are as far above the sea as they would be at the top of Mont Blanc, but they enjoy good health.

As the box of the cranium encloses the brain so as to leave no vacant space, it is evident, that when the heart injects blood with unusual violence, the strain at first is chiefly borne by the cranium itself, and not by the coats of the blood-vessels. Hence the arteries of the brain are not nearly so strong as those of other parts of the body.

The veins of the brain are also peculiar. Common veins would collapse by any sudden tension of the arteries, and if they did, insensibility or death would ensue, on account of the consequent stoppage of the circulation. The chief channels, therefore, for the refluent blood, instead of being common compressible veins, are what have been called *sinuses*, or grooves in the bone itself, with exceedingly strong membranous coverings, supported so powerfully, that the whole become in strength little inferior to complete channels of bone. The singular deviation in the structure of the cerebral veins from what is found elsewhere, and without which animal existence could not have continued, is one of those particulars which powerfully affect the contemplative mind, as proofs of the design which has planned this glorious universe.

From not adverting sufficiently to the circumstance which we are now explaining, of the cranium being a vessel which is always full and will only hold a certain quantity, misconception has prevailed among medical men with respect to many of the affections of the brain.

It has been said, for instance, that the substance of the brain cannot bear pressure with impunity, for that stupor immediately follows it, however produced. Now the truth is, that pressure produces stupor only when it stops the circulation. In wounds with loss of a large piece of the cranium, the brain will bear very rough handling, because if compressed in one part, it may extend in another, and the circulation remain free. But if the wound be small, pressure made through it instantly affects the whole brain, and the blood from below is prevented from entering.—Let one reflect for an instant on what happens to the head of the child during parturition, how often it comes into the world elongated and bent, almost as if it were of soft clay, and for the time hideous: yet the child lives and thrives as well as if nothing of the kind had happened.—The reason is, that the fœtal skull is soft, and pressure in one part is relieved by a corresponding bulging or extension in another, and the blood is not expelled.

Water in the head, again, is said to kill by this fatal pressure on the tender brain: but, in reality, it kills by mechanically arresting the circulation. Accordingly we see, that where the *fontanelle* still remains open, or where the *sutures* or joinings of the skull yield, water may accumulate to a great degree without causing disturbance.

A tumor in the brain, which would be of no consequence if the brain were unconfined, soon becomes fatal by checking the supply of blood.

If the substance of the brain at all increase and diminish in bulk, like muscles, &c. in the body below, all such changes must produce a considerable effect on the cerebral circulation and functions.

Effects of position on the circulation.

While a man is standing, the heart and arteries have to send the blood up to the head against gravity: and in the horizontal position, the blood may arrive with greater force, because gravity then does not resist. Hence head-ache from fulness of blood in the arteries of the head, is often relieved by the upright position, and increased by lying down.

Many people having a slight degree of toothache during the day, find it intolerable when they lie down at night, and are relieved again by rising and walking about. They often suppose that it is the cold which lulls the pain, but it really is the change of position.—The author knew a lady who had a *tic douloureux* that came on always when she lay down, and she was obliged to sleep for months in the sitting posture.

Delirium in fever has been checked at once by elevating the head. On account of the great relief thus obtained, some continental practitioners proposed to support the patient occasionally in a completely upright posture.

Apoplexy has often been brought on by a man bending his head down in the act of tying his shoe, or pulling on his boot.

Children and tumblers being much in the habit of placing their bodies in all positions, feel no inconvenience from having the head downwards, because arteries and veins always become strong enough to bear the pressure to which they are habituated; but to many old people accustomed to keep the head always up, the attempt would be fatal.

Ulcers on the legs are often obstinate and bleed, because the veins are too weak to support the lofty column of blood above them.—Hence the frequent counsel given in such cases to keep the feet raised upon a chair.

Many inflammations of the legs and feet become exceedingly painful when the limbs are in a hanging position, and the pain is relieved by laying them horizontally.

Many anasarcous or dropsical affections of the legs increase towards night, because during the dependent position of the legs through the day, the absorbents want power to lift the fluid: the swelling disappears again before morning.

When the heart has to send blood upwards, it seems to act more strongly than when the body is horizontal, and the pulse increases five or six beats in the minute: hence the common rule to lay a patient with hemorrhage in the horizontal position, that the heart may become tranquil, and allow the bleeding to cease.

Fainting from diminished arterial tension.

Fainting, which is a temporary cessation of the action of the heart, and thence, as explained above, of the action of the brain, is produced by several causes, and among others, when by any means the blood-vessels about the heart are rendered suddenly less full or tense than usual. It would appear that the heart being accustomed to a certain degree of resistance when it contracts, has its action disturbed when the resistance is much diminished.

Thus hemorrhage, from any cause, by lessening the general tension of the sanguiferous system, often causes fainting. The state is relieved by lying down, probably because the weaker action of the heart is then still sufficient to send blood to the head, until a gradual contraction of the whole vascular system reproduces the tension necessary to perfect action. A small quantity of blood taken away *suddenly*, affects the circulation nearly as much as a larger quantity taken *gradually*, because a certain time is required for the gradual lessening of vessels.

The operation of *tapping* for dropsy in the abdomen, that is to say, the suddenly removing a large quantity of fluid which had been compressing all the abdominal vessels, and keeping them perhaps only half full,—by allowing such vessels suddenly to receive again their natural quantity of blood, and thus producing a relaxation of the other parts of the vascular system, would often bring on fainting, but for the precaution used of tightening a broad bandage upon the body as the water flows.

Sudden parturition often causes faintness for the same reasons.

Even rising up suddenly from a bed or couch will cause an approach to fainting in weak people, or in those who have been long bed-ridden, probably because the heart having for a time been accustomed to send blood only in a horizontal direction to the head, does not in an instant exert the additional power required to lift an upright column with equal force; and because the blood does not then return to the heart, by the veins from the inferior parts of the body, so readily as before.

These various facts, now easily understood, form the reason of a rule which is a great modern improvement in the practice of the healing art, *viz.* in bleeding for the cure of inflammation, to take the blood away as *quickly* as possible. This subject deserves a little farther consideration.

A great proportion of dangerous diseases involve in their nature inflammation of some vital organ; and inflammation consists chiefly, as already stated at page 497, of a gorging or over-distention of the capillary vessels in the part. The nature of the capillaries, again, is such (page 495), that when not constantly filled by the pressure of the heart behind them, they gradually empty themselves towards the veins by their own action—as is seen in the disappearance of a mortal inflammation soon after the death of the person; in the fact of the arteries being emptied of blood after breathing ceases, &c. Now ever since medicine deserved the name of an art, practitioners have accounted the lancet their sheet-anchor in inflammatory disease; but it is only in late times, after the circulation of the blood was understood, that they have known the rationale of the remedy, *viz.* that it acts by diminishing vascular tension, and thence the action of the heart, and so allowing the small vessels to empty themselves by their own force, and to recover sufficiently to resist the return of an excessive load. It is still more lately that they have known and understood, how much more suddenly and completely the disease is cured by abstraction of a small quantity of blood *so rapidly*, as to produce fainting, than of a much larger quantity *so slowly* that only weakness follows. Judicious treatment now cures inflammation more certainly and better than was done formerly, yet with much smaller loss of the precious blood, and less danger of those diseases of weakness, or of a complete breaking-up of the constitution, which often follow great depletion. To induce faintness, *large* openings into the veins are made, and often into two veins at once, and the patient is kept in the upright attitude. Often thus an inflamed eye, which was as red as scarlet before bleeding, in a few minutes is rendered nearly of the natural appearance; and most intense inflammations of the brain, lungs, bowels, &c. yield in the same manner. In all these cases the faintness seems to be equally efficacious, whether it happens after the loss of ten ounces of blood, or of fifty; or even as sometimes occurs, without bleeding at all, after merely tying the arm in preparation.

Reflection upon these circumstances led the author to think that, in certain cases, the beneficial effects of blood-letting might be attainable, by the very simple means of *extensive dry-cupping*, alluded to at page 326; that is to say, by merely diminishing the atmospherical pressure on a considerable part of the body, on the principle of the cupping-glass used very gently, and thus suddenly removing for a time from about the heart, a quantity of blood sufficient to produce faintness. The results of trial have been such as to give great interest to the inquiry, and the author's first leisure will be devoted to the prosecution of it.—An air-tight case of copper or tin plate being put upon a limb, and closed by tying its leathern collar round the limb with a garter, on part of the air being then extracted by a suitable syringe, in an instant the vessels all over the limb become gently distended with blood; and as the blood is suddenly taken from the centre of the body, faintness is produced, just as by bleeding from a vein. The excess of blood may be retained in the limb as long as desired, for the circulation in it is not impeded. To produce a powerful effect with a slight diminution of pressure, more than one limb must be operated upon at the same time.

An instrument resembling the contrivance now described, was proposed about twenty years ago by a non-professional person, as a means of drawing all sorts of diseases out of the body through the pores of the skin. He enclosed a leg in an air-tight case, he then admitted steam to heat the limb, and relax the pores of the skin, as he said, and then he worked an air-pump to draw out the disease. He called the engine the *air-pump vapour-bath*. In various cases where its true action was desirable, although not understood by the proposer, nor judiciously managed, it proved beneficial.

The operation of applying tourniquets or bandages round the limbs, so as to prevent the blood from passing easily to and from them, may affect the action of the heart. It is said, sometimes, to have prevented the accession of ague. It is a means akin to those above described.

Because arteries are stronger than veins, a bandage may be put round a limb, tight enough to close the veins but not the arteries, and the limb will then swell beyond the ligature. By thus putting tight elastic bandages round all the limbs at once, and immersing them in warm water to favour the dilatation of their vessels, so much blood may be suddenly detained in them as to cause the person to faint. Such means, therefore, might also be used remedially.

When a *hernia* or other tumor is strangulated, it swells, and if not relieved, at last mortifies.

For the same reason, a tight handkerchief, or stock round the neck, will often retain the venous blood in the head, and cause apoplexy.—Strong pressure made on the jugular veins kills as certainly as if made on the windpipe.

Diffused pressure, like that made by rolling a bandage round a whole limb, or by the immersing it in fluid, must affect the circulation. The veins will be more compressed than the arteries, by reason of the distending force in them being less. Varicose veins, therefore, are usefully supported by a bandage or laced stocking. The reason why this manner of supporting assists so powerfully in the healing of ulcers on the legs, may be, because the support affects the capillaries and absorbents as well as the larger vessels.

Poultices, by their weight, produce a soft compression of the parts on which they are applied; and in certain cases, may benefit by mechanically squeezing the excess of blood out of weakened vessels.

The author has relieved the chronic inflammation of sprained ancles, by ordering the foot and leg, covered with an oiled-silk stocking, to be enclosed in a boot strong enough to support the pressure of fluid mercury, and to be then surrounded by this for an hour or more.—The effect is a pressure by the mercury on the weak vessels, of one pound to the square inch, for every two inches of the mercurial depth above the part.—A height of four or five inches gives the relief physiologists. Thus far, however, we know—that the ingredient called *oxygen*, forming a fifth of the atmosphere, is the most essential part—that by being breathed once, air is rendered unfit for farther respiration at the time—and that a man requires about a gallon of air per minute. Mr. Spalding and his companion who descended in one of the first used diving-bells, owing to the signal cord becoming entangled round the great rope of the bell which twisted in descending, could not make their want of air known above, and were both found dead when the bell was drawn up soon after, although the water had not been near them. Of a hundred and forty-six Englishmen who in the year 1750 were made prisoners at Calcutta, and were thrown into the close dungeon, called the *black-hole*, only twenty-three survived the hours of their confinement, and these had to make one of the most sickening recitals of human suffering which exists on record.

We know generally of the life-supporting action of air that it consists in some change operated on the blood, and that the function of respiration has to bring air and blood together in the cavity of the chest, that the change may take place. The blood is there moving along a part of its circle in vessels of extreme minuteness and thinness, and the air at each inspiration rushes in among these, so that every globule of the blood passes within its influence. The blood which arrives at this part of its course black and impure, from having served the purposes of the body, immediately after its exposure to the air enters the left chamber of the heart of a beautiful scarlet colour, and thence departs to carry new life to all parts of the system.

The minute vessels through which the circulating blood is strained in the chest do not hang loose in the cavity, but are supported by running through spongy masses, called the lungs, which consist chiefly of vessels and of thin membrane formed into cells. These cells at every inspiration are filled with fresh air through the cartilaginous windpipe which branches into them, and at every expiration the changed air is returned by the same channels to rise in the atmosphere.—The lungs of a child, before birth, are perfectly collapsed, or without the least air in their structure, and hence are dense enough to sink in water: after breathing they retain a portion of air, and will float. This fact has been accounted a test of whether a child had been born dead or alive; but as putrefaction, &c. will cause air to be in lungs which have never breathed, the criterion may be fallacious.

The chest is a large cavity bounded above and around by the ribs, back-bone, and sternum, and below divided from the abdomen or belly by a strong membranous and muscular expansion, called the diaphragm. The ribs, in the natural state, hang obliquely downwards from their attachments to the spine, and on being raised, they widen or increase the size of the cavity, as already explained at page 204. The cavity is farther enlarged by the descent of the diaphragm, which may be regarded as the floor of the chest, and as the roof of the abdomen, and which being naturally convex upwards like a dome, by contracting itself to a more flat condition, sinks out of, and enlarges the chest, while it descends into, and diminishes the abdomen.

Now when the chest is thus enlarged by the rising of the ribs and descent of the diaphragm, or by either singly, the air rushes into it through the mouth and windpipe, exactly as air rushes into a common bellows through its pipe, when the valve is shut and the two boards are drawn apart; and air is again expelled from the lungs by the contraction of the chest, as from the bellows when the boards approximate. Into both cavities air enters, because with the enlarging dimensions, the air within dilates, and becomes less powerfully tense, or resisting against the external pressure of the atmosphere, and more air rushes in until equilibrium is restored.—The air is expelled again by the contraction of the cavities, because, by being compressed, its elastic force or tension becomes greater than that of the external air, which it therefore easily repels and so escapes. —By immersing a common bellows in water and then opening and shutting it, the entrance and exit of the fluid is rendered still more apparent.

That the air admitted to the chest should have the fullest action on the blood passing there, it was necessary that the spongy mass of lungs in which the blood-vessels ramify, should occupy the whole of the cavity, and be equably distributed. Now while the equable distribution is effected by the elasticity or resilience which belongs to the structure of lung, the complete filling of the cavity is obtained, not by general attachments between the lungs and the ribs or sides of the chest, as might be expected, but by the following means, equally simple, and yet more perfect. The spongy mass of the lungs is completely covered by a strong membrane, called the pleura, as close in its texture as a bladder; between this membrane and a similar lining of the chest there is no air or empty space, and therefore, in the rising and falling of the ribs during respiration, this membrane remains always in contact with them, just as a bladder put into a bellows as a lining, with its mouth secured around the nozzle, is filled and emptied and remains in contact with the interior of the bellows, in all its states of dilatation, as if it were attached in a thousand places.—This construction allows the lungs to have a singular freedom of play during all the motions of the body; a freedom farther provided for by their being divided into five portions or lobes, of which three occupy the right side of the chest, and two are in the left, the heart occupying there the place of the third.—The right and left sides of the chest are formed into perfectly distinct cavities by the *mediastinum*, a strong membranous partition.—The mechanical disposition of the contents of the chest, as now described, is productive of certain consequences which it is important to understand.

If a wound be made in one side of the chest so as to admit air, the lungs of that side collapse in obedience to their elasticity mentioned above;

and when the chest then enlarges and diminishes in respiration, air more easily enters and leaves the cavity around the collapsed lung by the wound, than it can enter or leave the lung itself by the windpipe; because in the first case it has no force to overcome, and in the second the elasticity of the lung opposes. If such wounds, therefore, were made into both sides of the chest at once, even without hurting any part within, the person would still die of suffocation, because all the lungs would remain collapsed. To relieve this manner of suffocation, it would be necessary to press the ribs down so as to empty the chest of air as much as possible, and to keep the wounds close or covered while the ribs rose again; the air, of course, would then enter by the natural road, the only one left, to fill the chest, and would approach the blood in the pulmonary vessels as usual. In Benjamin Bell's system of surgery, which was long the manual of practitioners, from imperfect understanding of this subject, counsel was given the very contrary of that required, and, of course, a patient treated according to it must have been allowed to die.

In cases of dangerous hemorrhage from the lung, after a wound in the side, the proper practice is to allow the lung to collapse, as now explained, that the hemorrhage may be checked; and when the danger is past, the external wound is to be closed, that the natural action of the lung may again establish itself. — A man can breathe very well for a time with the lung of only one side of his chest.

In cases of hemoptysis, or spontaneous bleeding from the lungs, a disease so often fatal, life might be saved or prolonged by making an opening between two of the ribs, and allowing the lung to collapse. The affected lung is often clearly pointed out by circumstances of the case; and the opening, when properly made, would be little dangerous, as is proved by the safety with which water or pus is discharged from the chest.

The same operation has been tried as a forlorn hope in pulmonary consumption. This disease is often found in the lung of one side, while that on the opposite side is healthy; and as the alternate stretching and collapse of the diseased lung during respiration, and the contact of the air, powerfully prevent an ulcer from healing, or inflammation from subsiding, a new chance of recovery is given by allowing the diseased lung to collapse and remain at rest.—Some cases are recorded, where cure is said to have followed this operation, and certainly, where the circumstances are favourable for it, and where death must ensue unless this can save, it is worth trying.

When ribs are fractured, it is the practice to put a bandage round the chest, so as for the time to prevent the respiratory motion of the ribs, and the breathing is then performed by the rising and falling of the diaphragm or floor of the chest, as already explained—it bulges into the chest to lessen the cavity, and is again drawn down or flattened to increase it. A person with broken ribs is obliged to submit to this unnatural confinement: but it is the height of folly to inflict the same on healthy beings, as is yet constantly done, even to the destruction of health, by the fashion of bracing the body in tight stays.

The force of a healthy chest's action in blowing is equal, as stated in last section, to about *one pound* on the inch of its surface; that is to say, the chest can condense its contained air with that force, and can therefore blow through a tube of which the mouth is two feet under the surface of water. In sucking or drawing in air, the power is nearly the same.—In both these actions it is possible to use the cavity of the mouth separately from that of the chest; and the mouth being smaller, with stronger muscles about it in proportion to its size, can act more strongly. Some men can suck with the mouth so as to make nearly a perfect vacuum, or to lift water nearly thirty feet. In using the blow-pipe, an expert operator can keep up an uninterrupted blast by shutting the mouth behind while he inhales, and replenishing it as is required in the intervals.

In *coughing*, by a curious sympathy of parts, the windpipe is first closed for an instant, while the chest is compressing and condensing its contained air, and on then opening, a slight explosion, as it were, of the compressed air takes place, and blows out any irritating matter that may be in the air passages; just as the burst from the chamber of an air-gun discharges its bullet.—This shutting of the *glottis* to allow the compression of the air, and the subsequent opening to allow the discharge, may occur at very minute intervals, and many times from one fill of the chest, as is instanced in hooping-cough.—The action of cough is often produced, when the irritation is from a cause that cannot be removed by cough, as inflammation of the chest, or tubercles: or even when the irritation is in a distant part, and the action, therefore, is sympathetic, as when children are teething, or when the stomach is overloaded.

Sneezing is a phenomenon resembling cough, only the chest empties itself at one throe, with great violence, and chiefly through the nose, instead of through the mouth, as in coughing. The irritation that produces sneezing is generally in the nose; but, like cough, sneezing may occur from distant sympathies: witness that from worms in the bowels.

Laughing consists of quickly repeated expulsions of air from the chest, with the voice heard between them, but there is never complete closure of the entrance to the windpipe as in coughing.

Crying differs from laughing almost only in the circumstance of the intervals between the gusts of air being longer. Children laugh and cry in the same breath, and it is often difficult to mark the moment of change.

Hiccup is the sudden stopping of a strong inpiration at its commencement.

In *straining* to lift weights, or to make any powerful effort, the air is shut up in the lungs, that there may be steadiness and firmness of the person; and by the compression and condensation of air around the heart and large blood-vessels, the blood is determined violently outwards from the chest, and often rises to the head, with force that produces giddiness, or even apoplexy. The eye will become suddenly blood-shot at such a moment, from a small vessel giving way; or leech-bites will break out afresh. — The force of this pressure outwards is measured, as already stated, by a column of about two feet of blood; and this is therefore the measure of the additional arterial and venous tension in the body generally.

Suffocation is the name given to what happens when the supply of air to the lungs is in any way prevented. The blood, not then refreshed by the approach of the air, rises to the brain unfit for its purpose, and confusion of thought is immediately produced, soon followed by convulsion and death.

When this happens from a mechanical obstruction at the narrow entrance of the windpipe, as in croup by the tenacious films thrown off from the inflamed lining of the air-passages, life may be saved by making a new entrance for air through the windpipe lower down in the neck, and keeping this free by a little tube inserted, until the obstruction above be removed.—Where children die with croup, it is often not from the violence of the constitutional disease, but from matters thus accidentally sticking in the narrow entrance of the air passage.

In the cases of strangling and hanging, the tight binding of the rope or ligature bends inwards the cartilaginous rings of the windpipe, and shuts the air-passage. It may also cause apoplexy, by arresting the passage of blood to and from the head; and there may be dislocation of the cervical vertebræ of the spine.

In *drowning*, communication with the atmosphere is cut off altogether by the supernatant water, and if the chest were then to expand, it could receive water only instead of air. The nerves and muscles, however, at the entrance of the windpipe, being exceedingly irritable, are excited by the contact of any foreign matter, and shut the passage for a considerable time against the intruding liquid. It is on account of this action at the *rima glottidis*, that preservation of the life is often accomplished, after immersion in water and apparent death, when the body is recovered within a moderate time.

The apparatus of the Humane Society for the recovery of persons apparently drowned, includes a bellows for producing artificial respiration. This resembles a common bellows, except that, instead of the usual internal flap or valve, it has an external flap, made like a large flute-key, with a spring to close it, and obedient to the finger of the operator. The bellows receives its charge of fresh air by being expanded in the usual way, while the valve is open; it sends the charge into the lungs on being compressed while the valve is shut; it withdraws the charge again on being expanded with the valve shut; and the impure air is thrown out to the atmosphere on its being compressed with the valve open. These changes repeated and continued, produce the artificial respiration required. In addition to this means, for the recovery of suspended animation, it is necessary to restore natural warmth to the body, to rub the limbs in aid of the circulation, to administer stimulants by the mouth, &c.

It seems to be an error, and probably often a fatal error, in the present mode of treating persons apparently drowned, to use cold instead of warm air for the artificial respiration. While the important object of restoring the temperature of life is sought by all external means, it is a great inconsistency to be blowing cold air upon the internal surface of the lungs, which is more extensive than that of the whole body externally; for until that reciprocal action of the air and blood begins, which constitutes the slow combustion of natural respiration, every bellows-full of cold air admitted, brings back with it a portion of the remaining central warmth, and may thus exhaust, so as to make the recovery impossible—just as a fire which has fallen very low may be immediately extinguished by a bellows, which a little before would have made it blaze. Air might easily be heated for this purpose by pouring boiling water into a vessel containing air, and then connecting the bellows with that vessel by a fit pipe:—a quart of boiling water has heat enough in it to warm many gallons of air to blood heat. This plan would not only avoid the mischiefs arising from the cold air, but by giving warmth a little higher than that of life, might probably furnish the most useful of all stimulants to the parts about the heart. A healthy man can breathe with impunity, air that is considerably hotter than boiling water.

Late physiological investigations have shewn that the mechanical action of the chest in respiration is dependant upon the influence of the brain, so that it is disturbed or stopped when the brain is embarrassed: they have shewn also that the action of the heart is dependant on the breathing, but not on the brain, except as the cause of the breathing; for that respiration kept up artificially, will preserve the circulation and the life for a considerable time after the brain has altogether ceased to act, or has even been removed from the body. Now, as proved by some most interesting experiments of Mr. Brodie, certain poisons are fatal merely because they suspend for a time the action of the brain; through which suspension the actions of the chest and heart afterwards cease, and death ensues. But if in such cases the action of the chest be maintained artificially, the circulation and life of the body are for a time continued, and the brain may gradually recover from the effect of the poison, and resume its office. Thus certain cases of poisoning, which formerly would have been fatal, may now end in recovery.

But the most important application of this admirable discovery is to the treatment of cases of convulsion, particularly those occurring from teething or other irritations in infancy. The respiration ceases in them merely because the action of the brain is suspended; but if the respiration be continued artificially, the circulation and life will also continue for a time, during which the brain may recover itself, either spontaneously, or in consequence of remedies employed, and life may be saved. The same practice might be effectual in cases of spasm of the heart in grown persons.

The chest of an infant is comparatively so small, that it may be filled from the mouth and windpipe of a grown person, with air which has not descended to the lungs, or been rendered unfit for respiration; and on the chest being afterwards compressed by the hand, the air will return. The air may be blown directly into the child's mouth through a thin handkerchief laid upon it, or may pass through a tube inserted into the nostril or trachea: to prevent air from passing into the stomach, the larynx must be pressed against the œsophagus during its entrance.

A medicated air is generally inhaled from an oiled-silk bag, or from a light gasometer. (See page 398.) The advantages anticipated to medicine from pneumatic or aerial mixtures, when the compound nature of our atmosphere was first discovered, have not yet been realized; but the subject is still highly deserving of farther research.

THE VOICE AND SPEECH.

The chest and air-passages, with their parts, constitute the organs of voice and speech.

An inquirer into the constitution of the universe around him, meets with few things calculated more to surprise him, than that faculty in the human mind by which it can associate the ideas of objects with any arbitrary signs, so closely, that the ideas are afterwards excited by the signs almost as vividly as by the objects themselves. The inhabitants of China, for instance, have contrived many thousand grotesque characters, and determined what object each one shall recall; and a person who by study becomes familiar with them, may have his bodily eye poring over pages of crooked and unseemly scratches, while his mental eye sees only a pleasing succession of the most beautiful imagery of nature:—and these characters are intelligible to the deaf and dumb man as well as to him who speaks, and they serve as media of thought and communication through many provinces and countries of which the spoken languages have no common resemblance.

And if the ready remembrance of visible marks be wonderful, which have permanent existence, and often a certain resemblance to the things signified, how much more wonderful is it that an audible sign,—that is, a passing sound or fugitive breath—should serve as well; and that by a succession of mere sounds, different in every country, and changing from age to age, any train of thought may be made to pass through the minds of an audience, and to leave impressions as if from realities. Such, however, is the fact, and it is greatly owing to this, and to a correspondent faculty in man of producing easily a sufficient number of distinguishable sounds, that he owes his elevation above the brutes of the field. His godlike powers of intellect would have remained dormant and unknown, had he wanted the power of comparing his invisible thoughts with those of his fellow men, and of arranging and recording them by means of signs. Written language is a double remove from the objects themselves, being *visible signs* not of things, but of the *audible signs.*

The admirable apparatus by which man is enabled to produce a sufficient variety of sounds to answer his purposes, passes generally under the title of *the organs of speech;* because the combination of sounds which have meanings assigned to them is called speech. This apparatus consists chiefly of the larynx or cartilaginous box at the top of the windpipe for producing the voice, and of the short tube of the mouth for modifying it.

In the chapter on acoustics, we explained that sound is a name given to the effect produced upon the ear by certain tremblings conveyed to it generally through the medium of the air: and we explained how air, rushing from the human lungs through the opening at the top of the windpipe, causes the elastic lips of that opening to vibrate, and to excite the tremblings. We have now to show that this sound, in passing forward from the top of the windpipe, may be modified at the will of the individual, in a great and yet very simple variety of ways.

The modifications of voice easily made, and easily distinguishable by the ear, and therefore fit elements of language, are about fifty in number; but no single language contains more than about half of them. They are divisible into two very distinct and nearly equal classes.

Those of the first class are the simple voice, influenced only by the degrees in which the mouth or vocal tube is opened and elongated. They may be continued as long as there is breath to issue from the chest, and therefore are named *vowels* or *calling sounds*. The roman letters, A, E, I, O, U, as pronounced on the Continent, indicate the most easily distinguishable vowels. Sound passing through the mouth in its most natural state of relaxation, is heard as the modification expressed there by the roman E: if the mouth be then widened, it becomes A; if narrowed, we hear I; if the mouth be at the same time elongated and widened, we hear O; and if elongated and narrowed, we hear U. The possible number of vowels, however, is as great as the possible degrees in which the dimensions of the mouth may be altered; but although there are about twenty sufficiently distinguishable, few languages comprehend more than twelve. Modern art can produce the vowel sounds mechanically by means of tubes of certain dimensions.

The alphabets of Europe are very faulty, in not agreeing as to the characters for particular sounds. In English one letter is used for several sounds, as A in *water*, *far*, *fat*, *fate*, which are four perfectly distinct. In repeating the English alphabet, the A is pronounced as the broad E of the Italians and of Europe, and the E as the I. The English vowel I, is the diphthong AI of more correct alphabets; and the English U, is the dhipthong IU. In consequence of the changes which have taken place in England in the meaning of the roman letters, the natives have greater difficulty in learning modern continental languages;

and their pronunciation of the ancient languages appears ridiculous and is almost unintelligible to all but themselves. The same cause renders the pronunciation of English difficult to foreigners, and narrows much the cultivation of English literature in other countries.

To explain the second class of the modifications of sound, we may remark, that while any continued or vowel sound is passing through the mouth, if it be interrupted, whether by a complete closure of the mouth, or an approximation of the parts, the effect on the ear of a listener is so exceedingly different, according to the part of the mouth where the interruption occurs, and the manner in which it occurs, that many most distinct modifications thence arise. Thus any continued sound as A arrested by a closure of the mouth at its external confine or lips, ends with the modification expressed by the letter P, and the syllable AP is heard; but if the sound be arrested at the back of the mouth by the tongue rising against the palate, we hear the modification expressed by the letter K:—the ear is equally sensible of the peculiarities whether the closure precedes the continued sound or follows it.—The modifications, then, of which we are now speaking, are not really sounds, but only manners of beginning and ending sounds; and because they can only be perceived in connexion with a vocal sound, they are called *consonants*.

There are in the mouth considered as a vocal tube, three situations, in which interruption of voice or breath may most conveniently be made, and there are six modes of making it at each; so that eighteen distinct interruptive modifications or consonants hence arise.

The three great *oral positions*, as they may be called, are,

1st. At the external confine of the mouth, or lips, giving the *labial* consonants.

2d. In the middle of the mouth where the tip of the tongue approaches the palate behind the teeth, producing the *palatal* modifications.

3d. Near the back of the mouth, where the body of the tongue approaches the palate, giving the *guttural* modifications.

Between the first and second positions, two *dental* sounds are produced, marked *th*, and explained below.

The *modes* in which the voice or breath may be affected in passing through each of the three positions of the mouth, are the following *six*.—(In pronouncing experimentally, it is better to let the vowel be heard before the consonant than after it, as by saying AB instead of BA.)

1st. *A sudden stoppage*, producing what may be called a *mute* articulation: *viz.* P, in the labial position; T, in the palatal; and K, in the guttural. (See here the general table of articulations at page 560.—The table may be considered as representing the tube of the mouth, with the letters placed in it, so as to shew where they are severally produced.) A mute may also be made by stopping the breath exactly at the teeth, giving a truly *dental mute*; but it is hardly distinguishable from the *palatal mute* just behind it, and is not used.—Some awkward speakers substitute it for the proper one, and are said to *speak thick*. If the sides of the tongue be depressed after taking the position required for T, the sound L is produced.

2d. A sudden shutting, as in the last case, but the voice being allowed to continue until the part behind the closures be distended with air.—This produces the *semi-mutes*, B, D, and G, (in its hard sound as in pig), for the three positions. There might be a dental *half-mute*, but it is no more used than the *dental mute*, and for the same reasons.

3d. The positions are closed as for the mutes, while sound is allowed to pass by the nose, making the *semi-vowels* or *nasals*, M, N, NG, for the three positions.—NG (as in *king*) is a simple sound, although our imperfect alphabet has no single letter for it. The nasal sound of the French language which gives it so great a peculiarlity, approximates to the English NG, but differs from it in the sound passing by the mouth, as well as by the nose. It is represented by *on* in the table.

4th. When breath only (or whisper) is allowed to pass at the three oral positions nearly closed, sounds are produced which we call *aspirates*; *viz.* F, TH, and CH. The TH is heard in the word bath, and is the ϑ of the Greeks. The CH is heard in the Scotch word *loch*; in the German, *ich*, and is the χ of the Greeks. The soft, *palatal* aspirate TH, is not so easily made as the *dental*, which is heard on pressing the tongue gently against and between the teeth, and allowing the breath to pass all around. The *dental* aspirate is therefore generally substituted for the *palatal.* The letter S is the *hard palatal aspirate*, and differs from the *soft aspirate* TH, in the breath being allowed to issue only by a narrow space over the centre of the tongue, instead of on all sides, as for TH ; and for S, the breath issues also with more force. French people, on first attempting to pronounce TH, always substitute for it the S or the Z, which is nearly related to S, as explained below. The author has enabled several to pronounce the TH at once, and perfectly, by explaining its nature as is done above. If the sides of the tongue be depressed while pronouncing S, we make the simple sound expressed by the English double letter *sh ;* just as by depressing the sides of the tongue while making T we produce L.

5th. By using *voice* as we do *breath* or *whisper* for the aspirates, we make the sounds called *vocal aspirates, viz.* V, TH, Z, J, and GH. TH *vocal,* is heard in *bathe,* as contrasted with *bath ;* Z is the S only with *sound* instead of *breath ;* SH pronounced with *voice,* becomes the J of the French in the word je, or the sound heard in the middle of the English word *vision.* GH is a simple sound used in German, but not in English.

6th. By shaking the approaching parts in the three positions, we make *vibratory sounds,* of which the middle position gives the common R, and the only one used in English. Some bad speakers, however, in England, make the *labial vibratory* by shaking the P in such words as *property ;* and many use the *guttural,* which is the *burr* of

Northumberland, and the common affectation in Parisian speech, termed *parler gras*, or *grasseyer*.

Table of articulations.

Labial.	Palatal.	Guttural.		
P	T. L	K		Mute.
B	D	G		Semimute.
M	N	ng	on	Semivowel or nasal.
F	th. S. sh.	ch	H	Aspirate.
V	th. Z. J	gh		Vocal aspirate.
pr	R	ghr		Vibratory.

Remarks.

The sound of H does not belong to any of the three positions; and, indeed, is merely a forcible passing of the breath through the back part of the mouth or throat.

CH, in such words as *chain*, is T before SH.

J, as heard in the English name *John*, is a compound sound, *viz*. D before the simple J of the table, which is the S of *vision*.

LL. The liquid or double ll of the French, as heard in the word *paille*, is merely l with the letter y begun to be pronounced after it. It is heard in the English words *billiard* and *halyard*, and would be their terminating liquid were the syllable *ard* not pronounced.

GN. The soft gn of the Italians and French, is the English *n* with y begun to be pronounced after it. It is heard in our word *tanyard;* and in the Italian words *pegno bagnio;* and in the French word *craignent*.

C, in English, stands always either for S or K, as in the words *certain* and *car*, and has no sound proper to itself.

Q expresses a compound sound, *viz.* of the letter K, with U following it.

The consonants are best heard by sounding them with voice before them; that is, by making them rather terminate a syllable than begin it; pronouncing thus eb, ed, eg, rather than their common alphabetical names, be, de, ge.

The labial sounds may be made either by the two lips, or by one lip and the opposite teeth. F may be pronounced, for instance, by the lips only, or by the lips and teeth; and some persons awkwardly make it by the under teeth and upper lip.

The letters Y and I, in most modern languages, stand for nearly the same sound. In English, for instance, *bullion* and *minion*, might be written *bullyon* and *minyon*, without suggesting a change of pronunciation. In the words *yard*, *you*, *yes*, &c., the Y is a short I, very closely joined to the following syllable.—W is also thus a short U.

Lisping is chiefly the habitual substitution of the aspirate TH for the S and SH.

Whispering is articulation without voice; that is to say, articulation while breath only is passing.

Stuttering, *stammering*, or *hesitation of speech*, are terms implying an interrupted articulation, accompanied generally with more or less of straining and distortion of feature. It is remarkable with respect to this defect, that scientific or regular medicine possesses as yet no cure for it, although the frequent success of non-professional, and often ignorant individuals, by some mode of treatment, which they bind their patients by oath not to divulge, proves the cure both to be possible and not difficult.—The author's attention was drawn to this subject some years ago by an interesting case which was submitted to him; and it was in reflecting upon the subject, with a view to treat that case, that he framed the analysis of articulations contained in the preceding pages, and drew up the few observations which are now to follow. A cure was obtained; but as there was a favourable peculiarity in the case, and as the author has not had leisure or opportunity since then to pursue the subject farther, or to ascertain in what respects the plan then tried may agree with that employed successfully by others, he gives his remarks merely as continued elucidation of the subject of speech.

Command over the organs of speech is acquired in the same way, as over all the other muscular organs of the body;—as those for walking, skaiting, fencing, performing on musical instruments, &c.;—that is to say, at first, a distinct act of volition is required for every individual muscular movement; but the law of association or habit soon rendering the actions easier with each successive repetition, at last forms them into connected tribes or trains, which appear as obedient to a single wish as the separate elements originally were. A child exerts as distinct and powerful a volition at first to pronounce the syllable *pa*, as after some practice to double the syllable and make *papa;* or after still more practice, to pronounce the longest and hardest word of its language:—nay, at last, where there is strong and healthy power of association, complete sentences, and even rounded periods of eloquence, are poured out like single words, the mind of the speaker seeming at liberty after each sentence or period is begun, to meditate and prepare that which is to follow. The faculties of locomotion and of speech being acquired in infancy and early childhood, persons no more recollect how they came, than how their limbs grew; but the gradual progress described above, may be watched by any individual of mature years in his own person, while he is learning to play on a musical instrument. He will find, that at first every finger which is moved to produce a note, obeys a distinct thought and volition; that soon short trains of connected notes become obedient to the will like a single note; that by degrees such trains or passages become longer and longer, until at last, the instrument is as obedient to the practised player, as voice is to the singer, or speech to the orator, and any sweet modulation may flow on under the guidance almost solely of sensation and association.

There is great original diversity among individuals as to their powers of association, and therefore, also, as to their aptitude for acquiring the various muscular faculties. Thus some children walk well before a year, others require a much longer time, and some never succeed until they have had lessons of the dancing master and drill serjeant.—So, again, many people learn easily to play on musical instuments by ear and imitation, but others must begin by the study of written notes, and of the precise *fingering* by which each note is produced on the instrument; and many without the notes constantly before them cannot play at all.—So again, all persons may be said to learn to speak at first by ear and imitation; but many grow up to a certain age with defects, which judicious lessons from parents or other tutors are required to remove; and there are some, like stutterers, who from naturally weak or irregular association, retain defects which no ordinary teaching can cure. Now it appears that an analysis and scale of articulate sounds, with minute description of the organic actions required to produce them, such as for musical performance is possessed in the *gamut* and rules for fingering, should give the same assistance to the speaker, which the gamut gives to the player. The table and analysis contained in the preceding pages is intended to supply this information. It is constructed, from minute consideration of the organs of speech in action. It agrees in many respects with the common grammatical divisions of elementary sounds, while in others it pursues the analysis in a different way, and considerably farther. A person who understands the table, while he speaks, will have an intelligent perception of what he is doing, as well as the parrot-like faculty of habit or of repeating by rote, and thus will command any desired sound by two powers intead of one. And as a musician whose ear is not very retentive may think of his written notes and their relation to his instrument when his musical memory fails him, so may a stutterer, when hesitating at any sound, think of the letter which represents it, and of the position of the organs required by that letter; and thus by frequent practice in making the particular combinations of sound which are difficult to him, he will strengthen the useful habit, and may overcome the defect.—Stuttering, in some cases, might be relieved at once by a determination to open the mouth and allow simple sound to pass, whenever any position of the mouth threatens to become spasmodically permanent.

The study of the table of articulations leads to the immediate correction of many minor defects in utterance, and is calculated to facilitate the acquirement of foreign languages. A lisping person, for instance, is cured at once, by being told that the tongue must not touch the teeth in pronouncing the letter S; and a Frenchman who deems it impossible for him to pronounce the English sound of TH, discovers that he cannot avoid doing so if he rests his tongue against his teeth opened a little, and then forces breath or sound to pass between the tongue and teeth.

Several of the modern languages of Europe consist of nearly the same elementary or radical words, and the differences among them are chiefly in the prevalence of certain terminations, and in the preference of one or other of some of the related and convertible sounds classified in the analysis given above. A student, therefore, who by analytical investigation, or considerable practice, has become impressed with the peculiar genius of each language, may almost invent, before minute study, the majority of those words belonging to each, which have sprung from a common origin. This remark is so true with respect to the languages of Italy, Spain, Portugal, and even France, that to persons familiar with them, they are at last listened to rather as the same language spoken by different individuals, than as languages in themselves different.

Ventriloquism is the name commonly given to the art by which an individual can assume characters of voice and speech which are not natural to him, and can thus, alone, imitate closely a conversation held between two or more persons.

The most remarkable diversity is obtained by speaking during inspiration, instead, of as usual, during expiration. The voice so produced is more feeble than ordinary voice, and when other means are used to help the illusion, it gives very completely the idea of a boy calling from the bottom of a pit, or from the interior of a chimney, &c.

Other striking varieties of voice are produced by speaking with a more acute or grave pitch than usual, and with different degrees of contraction of the mouth; but these may be more properly called *imitations* than *ventriloquism*.

A person, by a little practice, may acquire the power of producing, without the slighest apparent motion of mouth or countenance, all except the labial articulations; and of these the F, V, and M can be imitated by parts behind; hence by avoiding words in which P and B occur, a person may speak without visible movement of the organs, and if he assume the attitude of a listener, he will make the deception of ventriloquism complete. The idea which some authors have had, that the articulations of the ventriloquist are not produced by the tongue and mouth, as in common speech, is altogether an error. The art, carried to a certain degree, is not very difficult, as any person may ascertain who tries it after studying minutely the nature of common speech.

The variety of effect in sound which the human organs are capable of producing is truly surprising. There are adepts in the art of imitations, who not only mimic the speech of all ages and conditions of human nature, but the songs of birds, the cries of animals, and even the sounds produced among inanimate things. Many of these performances become in the highest degree ludicrous, and furnish favourite amusements in our theatrical exhibitions. A Mr. Henderson, of London, about the end of the eighteenth century, used to *kill his calf*, as he called it, to crowded houses every night. Having dropped a screen between him and the audience; there soon issued from behind it, all the sounds, even to the minutest particular, which may be heard while a calf is falling a victim in the slaughter-house;—the conversation of the butchers, the struggling and bellowing, and quick breathing of the frightened animal, the whetting of the knife, the plunge, the gush, the agony;—and, disgusting as the idea is in itself, the imitation was so true to nature, that thousands eagerly went to witness the art of the mimic.

The following cases of inanimate sound may be closely imitated by the mouth—the working of a grindstone, including the rush of the water into which it dips, the rough attrition of the steel upon it, and various changes with the change of pressure;—the working of a saw cutting wood;—the uncorking of a bottle, and the noise of decanting its contents;—the sound of air rushing into a room by a crevice or key-hole in a winter night,—and many others.

It has already been explained that voice depends on the vibration of the two edges or lips of the slit-like opening of the glottis, by which the air passes to and from the windpipe.—The number of vibrations in a given time, or the pitch of voice, depends, of course, on the length and tension of these edges. The length is varied by the positions of the arytenoid cartilages, and the tension by the action of small muscles which act on these; and the cavity of the mouth is enlarged or lessened to accord with the number of vibrations, by the rising or falling of the tongue and larynx which form its bottom. The peculiarities of individual voices must depend on the size and firmness of the cartilaginous box of the larynx, the strength of the muscles of the chest which force the air through the glottis, and the pliancy of the moving parts.

The glottis is smaller in women than in men, and hence their pitch of voice is higher: with reference to music, it is generally an octave or eight notes higher than that of the man.

The voice of a boy, in regard to pitch, is generally the same as that of a woman; but at the age of puberty, the sounding organs in the male enlarge suddenly, and render the voice stronger than before, and by about an octave graver. The voice of a eunuch is the voice of a boy continued, because the change called puberty does not take place in him.

Complete loss of voice, for longer or shorter periods, is often experienced in fluctuating states of health. The vibrating, and therefore sounding edges of the glottis, are usually kept tense by the operation of certain muscles: but if these cease to act owing to the state of the nerves which govern them, the slackened edges will not vibrate as required, and the voice is lost. Slight colds suffice in many people to produce this effect: in others it comes as a mark of morbidly sensitive or delicate nervous system, and follows fatigue, or any other cause of debility. Articulation is not destroyed by loss of voice; and whispering answers passably the end of vocal speech.

No intelligent mind can meditate on human speech, and its influence in the world, without being roused to vivid admiration. But for speech, the most gifted individuals that have lived, had they existed at all, could have been little superior in their worldly state to the leading oxen of our herds, or to leading monkies in the woods. Even at the present day, among the natives of Australasia, where language may be said scarcely yet to be known, human nature is seen thus shockingly debased. On the other hand, in the history of the world, we may trace, as a consequence of speech, the following progress in art and civilization. Fathers by language have communicated their gathered observations and reflections to their children; these, again, have transmitted the inheritance with gradual accumulation to new descendants; and so on to the present day: and when the precious store had increased, until the simple powers of memory could retain no more, the art of writing arose, making language visible and permanent, and enlarging without limit the receptacles of wisdom. Printing came last, and now rolls the still swelling flood of knowledge into every hamlet and every hut. . Thus language, at the present moment of the world's existence, may be said to bind the whole human race of uncounted millions into one gigantic rational being, whose memory reaches to the beginnings of written record, and retains imperishably the important events that have occurred; whose judgment analyzing the treasures of memory, has already discovered many of the sublime and unchanging laws of nature, and has built on them the arts of life, and through them pierces far into futurity, seeing distinctly events that are to come; and whose eyes, and ears, and observant mind, are at this moment, in every corner of the earth, watching and recording new phenomena, for the purpose of still better comprehending the magnificence, and simplicity, and beauty of creation.

THE DIGESTION.

The doctrines of fluidity, illustrating and illustrated by certain phenomena of digestion.

The animal body may be seen at first, in the maternal ovary, as a single speck of mucus; but from possessing life—wonderful life—the little nucleus soon gathers to itself substance from around, and increases in bulk. In the beginning it remains attached to the body of its parent, and draws the material of its increase from its parent's blood; but after a certain time it is alone, and left to its own resources. We then see brought into play that extraordinary apparatus which we are now about to describe under the name of the *digestive* or *assimilating organs;* an apparatus which, out of almost any kinds of dead animal or vegetable matter, can build up the beautiful living body to perfect maturity of size, and form, and faculty.

Not only do animals require to take in and assimilate new matter while their bodies are growing, but after maturity also, in order to repair the waste of constant action. Fuel and water to the steam-engine are not more necessary than aliment to the living body.

Some of the less perfect animals take in sustenance like vegetables, by absorbent tubes that open on their surface; but by far the greater number receive it first into an interior cavity, where it undergoes certain preparation, and is then submitted to internal absorbents which drink up what is required, and mix it with the circulating blood. This internal cavity is called *a stomach.* As to form and appendages, it differs exceedingly in different animals, according to the nature of the substances which serve the purpose of sustenance, and to various other circumstances.

In man the food is received by the *mouth.* It is there first broken or torn into small portions by the *jaws*, armed with cutting and grinding points, called *teeth ;* at the same time a fluid called *saliva* pours out from glands around, and reduces the food into a pulpy mass; it is then pushed back by the *tongue* into the opening of the long tube called the *gullet* or *œsophagus*, which by successive contraction of circular fibres, propels it down to the pouch of the *stomach*, placed under the edges of the left ribs.—From the internal surface of the stomach a liquor oozes or distils, called the *gastric juice*, the most general solvent in nature, and which attacking the received food, soon reduces it, of whatever kind, to the state of a pultaceous mass, named *chyme ;* in this state it enters the *intestinal* canal continued from the stomach, and as it there gradually passes on, it receives a mixture of bile and pancreatic juice poured out from the liver and pancreas. After this mixture, a chemical decomposition and separation of parts takes place, and the pure nutriment of the body appears as a milky fluid floating among refuse. This milky fluid, called *chyle*, is taken up all along the canal by the numberless absorbent mouths of the vessels called *lacteals*, and is then carried to the *thoracic duct*, and so into the blood, to supply waste. The intestinal canal is about six times as long as the body, affording therefore a very extensive surface, from which absorption may take place. The remnant of the chyme which the absorbents refuse, continues its journey onwards, and is discharged.

Much of the process which we have now described is *mechanical*, as will appear immediately; other parts of it are *chemical*, such as the solution of the food by the gastric juice, the separation of the milky chyle, &c.; and parts are *vital*, such as the afflux, just when wanted, of saliva, gastric juice, bile, &c., and the muscular and absorbent actions. He who neglects any of these three classes of particulars, can have but a very incomplete acquaintance with the function.—We proceed now to explain the mechanical or physical circumstances connected with digestion.

The abdomen may be considered as a vessel full of liquid, in which therefore there is pressure in all directions, and increasing with the depth, (see hydrostatics), and increased also by the action of the surrounding muscles which form the sides of the cavity.

The justness of this view of the abdomen becomes evident, when we consider that moistened or semifluid food descends into the stomach, that drink follows, that gastric and other juices are then poured out to mix with the food as it passes on to occupy the whole length of the intestinal canal; and that the intestines externally are perfectly smooth, and moistened by the constant secretion of a lubricating serum, so that they slide among each other, without sensible impediment from friction. The abdomen, therefore, may be compared to a roundish smooth vessel filled with a thich fluid which is farther contained in a perfectly pliant and smooth-coated tube.

Thus the contents of the stomach and bowels, in a living man, are supported like water in surrounding water, and therefore, if the whole be of equal specific gravity, they cannot descend or advance by their weight. Neither can any general pressure, or contraction of the surrounding parieties, hasten, except during expulsion, the motion of contained matter, as has, however, often been supposed; nor can it help to empty one part into another, the stomach, for instance, or the gall bladder into the small instestine.

But, for the same reason, the very slightest contractile action of any containing part will be sufficient to propel its contents; gravity as a resistance being neutralized by the surrounding fluid.—And when the stomach or gall bladder, or any part of the intestinal tube, becomes so full, as to put the elasticity of the coats ever so little upon the stretch, that circumstance alone will cause a discharge of the contents, unless some muscular action oppose.—The natural action of the intestinal canal is a successive contraction of its circular fibres from above downwards, propelling the contents, just as if a small ring or tube were put round it and pushed forwards.

These considerations make evident the common error of supposing, that vomiting can by the sudden compression of the abdominal viscera, *mechanically* emulge or clear the obstructed biliary ducts.—If general pressure of the abdomen could produce this and similar effects, a descent in the diving-bell should be a powerful remedy; for nearly fifteen pounds on the inch is added to the ordinary abdominal pressure, at a depth of thirty feet in water.

We hence see also the kind of error into which our predecessors fell so generally, when they attributed much of the digestive power of the stomach to its simple pressure upon the food. The idea probably arose from the contemplation of the stomach or gizzard of a fowl, which is a powerful gristly substance, answering the purpose of a mouth and teeth, as well as of a stomach.

It is an error also to suppose that fluid quicksilver, which is sometimes given to remove obstruction, runs through the bowels simply by its weight. On first entering the loose small intestine, it must drag the part to the bottom of the abdomen, and the whole intestine must pass there nearly as a rope passes through a ring fixed to the floor. When the mercury arrives at the part of the intestine called the *cæcum*, where the course becomes upward along the fixed arch of the colon, it probably can be dislodged only by the patient lying down. Any useful operation of quicksilver, in such cases, may be from its acting as a stimulant to the bowels, by dragging or displacing them, in the manner above described.

When the abdominal muscles, which are the containing sides of the cavity, become tense, whether from unusual fulness of the cavity, or from their own action, as in any of the straining exertions, a variety of important mechanical effects are produced. Thus

A full stomach produces—tension and projection of the belly—projection of the diaphragm into the chest, causing hurried breathing, and impeding speech and singing—expulsion of blood from the abdominal vessels, and therefore, congestions elsewhere, as in the arteries of the head, sometimes producing apoplexy.

Abdominal fulness, as in *dropsy*, *tympanitis*, *corpulency*, *pregnancy*, &c., produces most of the effects now mentioned, in an aggravated degree. If dropsy be allowed to proceed too far without tapping, the patient will die of suffocation from the rise of the diaphragm.—The external veins of a dropsical person are generally turgid, because the blood is pressed into them out of the abdominal cavity. In tympanitis, or windy dropsy, the viscera hang down in the abdominal cavity, and the air occupies the upper part; while in common dropsy, they float about and are supported.

Straining or strong action of the abdominal muscles, takes place with almost every bodily exertion; for the abdominal muscles are the antagonists of the great muscles on the back and about the spine, and must come into play with them, to give firmness and rigidity to the trunk of the body. This may be seen remarkably in the actions of lifting, running, wrestling, &c. As the abdominal muscles cannot act in a continued way and strongly, unless the ribs from which they arise be nearly fixed: at such times the ribs are not only supported by the intercostal muscles, but by the air in the chest, confined by the closure of the air-passages in the throat: hence there is generally compression in the chest when the abdomen is compressed, and the blood is squeezed towards the extremities from both cavities at once. It is important to remark also, that in what are called the strong actions of the chest, as *coughing*, *sneezing*, *blowing*, &c., the abdominal muscles are the great agents. By pulling down the ribs to which they are attached, they narrow the chest, and by compressing the abdominal contents, and and thus raising up the diaphragm, they shorten the chest.

The following are examples of the effects of straining.—Lifting a great weight, or making any strong exertion, drives the blood up to the head, as marked by the sudden redness of the face.—Coughing will cause closed leech-bites to bleed afresh, and sometimes will overcome the action of the sphincter of the bladder or rectum, or will produce vomiting.—Straining to empty the bladder, rectum, or womb, or the effort of vomiting, will cause the rupture of a blood-vessel in the white of the eye, and consequent effusion of blood there.—Apoplexy often happens under the same circumstances, from breaking of a vessel in the brain.—The rupture of a varicose vein, or of aneurism, generally happens during exertion. —And then also the protrusion may occur at any weak part of the abdominal cavity, of some portion of its contents, producing what is called *hernia* or *rupture*.

Vomiting is produced chiefly by the action of the abdominal muscles, and not by the contraction of the stomach, as was long supposed.—The stomach has been cut out of a living animal, and a sheep's bladder has been substituted for it, and filled, and on then injecting an emetic drug into the veins, vomiting has taken place, as if the stomach had been unhurt; proving that general abdominal compression is sufficient to eject by the gullet without proper action of the stomach. Thus to prevent regurgitation of the food, the upper orifice of the stomach requires to be strongly closed, like the sphincters below.

The use of a small pump,—in this application called the *stomach-pump*,—has been introduced into practice within a few years, for removing poisons from the stomach where the action of vomiting cannot be excited. It has already saved many lives. It resembles the common small syringe, except that there are two apertures near the end instead of one, which, by valves in them, opening different ways, become what are called a *sucking* passage and a *forcing* passage. When it is desired to extract from the stomach by the pump, it is worked while its sucking passage is in connection with an elastic tube leading to the stomach, and the discharged matter escapes by the *forcing* passage; when desired, on the contrary, to inject by it, the connection of the openings and the tubes is reversed.

As a pump may not be always procurable when the occasion for it arises, it is important for the profession to be aware, that a simple tube will, in many cases, answer the purpose as well, if not better. If the tube be introduced, and the body of the patient be so placed that the tube forms a downward channel from the stomach, all fluid matter will escape from the stomach by it, as water escapes from a funnel by its pipe; and if the outer end of the tube be kept immersed in liquid, there will be during the discharge a pumping action of considerable power. On changing the posture of the body, water may be poured in through the same tube to wash the stomach. Such a tube might be rendered a syphon, if desired, the necessary preliminary suction being made by the mouth through an intervening vessel.

But there is still an easier mode, than either of those already described, of dislodging poison from a torpid stomach, and the author has used it successfully, *viz.* merely to place the patient so that his mouth shall be considerably lower than the stomach,—as when a man's body is lying on a sofa, and his face is brought near the floor,—and then to press on the stomach with the hand. The cardiac orifice opens readily in such a case, and the stomach empties itself like any other inverted vessel.

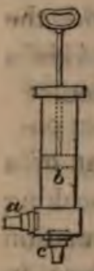
Useful as the pump may prove in evacuating the stomach upon occasions, its more ancient office of injecting the enema is still the most important:—and recent experience seems to shew that the injection of fluid *per anum*, may become a remedy of more extensive utility than had yet been suspected. From an erroneous opinion, that what has been called the valve of the cœcum acts as a perfect valve, allowing passage forwards only, few practitioners have ventured to order much liquid to be injected, for fear of overstretching or bursting the lower part of the gut;

and the possibility of relieving disease above the supposed valve had scarcely been contemplated. It is now ascertained, however, that fluid may be safely injected, even until it reach the stomach.— Perhaps few, if any cases of obstruction of bowels could resist the gentle force of penetrating water, and if so, a mechanical remedy of certain effect may be substituted for the drastic purgatives and pernicious bleedings now used, and often used in vain.

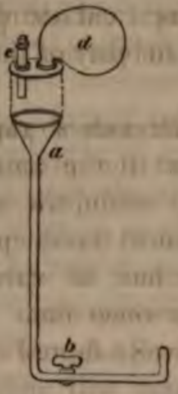
From what has been said above of the abdomen and the intestinal canal, it appears that an injection tends to spread itself evenly over the whole. This may be rendered obvious to sight by throwing a sheep's intestine, recently extracted, into a bucket of water, and then pumping water in at one end. A stream will issue strongly at the other end, although several feet distant, almost immediately, and without any intermediate part having become sensibly tense. Of course, in the living body, where there may be spasm or obstruction, the liquid must be thrown in against resistance very gradually.

That case is called *introsusception* of the bowel, where an upper portion falls, or is received into a portion below, and the receiving part then, mistaking the received for descending food, holds it fast. This occurrence forms a complete obstruction, and generally proves fatal. Many infants, with irritable bowels, die of it.—Now a copious enema, such as we have described above, is almost a certain cure. The liquid advances until it comes to the part where the portion of gut has been swallowed by gut below; and as it cannot pass without pushing the introsuscepted portion back to liberty, it effects the cure.

The *perpetual syringe*, or *little valved pump*, lately introduced in applications to the animal body, and which can inject or withdraw any quantity, is very superior for almost every purpose to the old syringes which had no valves, and could therefore inject only once their fill without being removed. With well-adapted additional apparatus, the same pump will answer for throwing up the enema, for clearing the stomach, transfusing blood, injecting the bladder, exhausting cupping-glasses, drawing the female breast, &c. No surgical apparatus will now be complete without one. The annexed outline represents such a syringe. The opening *c* is rendered a *sucking orifice*, by a valve at it, which opens inwards; and *a* is the forcing orifice, owing to a valve, which opens outwards: *b* is the piston, and *d* is the handle. The valves may be variously made, or a single *double-way-cock* may be used instead of both. Convenient dimensions for the syringe, are four inches for the length, and three quarters of an inch for the diameter.



In a case of diseased rectum, where it was necessary to use an enema daily, or oftener, the *enema funnel*, represented below, was found more manageable by the patient than any other instrument. If the tube *a b* be about two feet long, the



liquid column contained in it will overcome the ordinary abdominal resistance; but if a very short tube be used, there must be, instead of an open funnel, a close vessel, as represented here by the dotted line, having a bladder of air *d* connected with it, and a bottle-neck and cork, or cock, at *c*, for admitting the enema. On pouring in the liquid at *c*, the air in the vessel *c a* is forced into the bladder, and on then closing the opening at *c*, and compressing the bladder, it is evident, that any desired degree of injecting pressure may be exerted on the enema. This apparatus is both cheaper and more simple than any syringe, and is equally effectual; and the bladder never being wetted, lasts long: *b* is a cock kept shut until the moment of injection.

By viewing the abdomen in the true light of a vessel or bag filled with liquid which is seeking to escape in all directions, we have the explanation of several circumstances of *hernia* or *rupture*, in which accident some part of the containing sides of the abdomen gives way, and allows a portion of the viscera to escape, so as to form a tumour under the skin.

Hernia is produced by all causes which in any way strain or weaken the muscles: as by leaping, lifting great weights, coughing and sneezing, lying with the belly acoss a bench or yard, as on ship-board, over-distension by eating and drinking, corpulency, dropsy, pregnancy, debility of muscle from dissipation, &c.

The reason that a rupture increases so rapidly after it has once begun is, that the protruding part is truly a fluid wedge, of which, therefore, the opening force is proportioned to the diameter. This shews the singular importance of arresting the accident in its very commencement. The trusses used to repress rupture were described at page 223.

In attempting to return any part of the abdominal contents which may have escaped as a rupture, we should recollect, that a soft uniform pressure or squeezing exerted upon the tumour by the hands of the operator, if greater than the internal pressure of the abdomen, is slowly pushing back again any fluid matter that can ooze inward from the tumour; and by thus gradually lessening its size, may effect the desired object, without the necessity of trying the last resource of cutting the parts to widen the inlet. When, in such a case, an operator sees clearly with the mind's eye, what is passing under his hands, his efforts may thence often be successful, where those of a less intelligent individual would fail. No man practises medicine long, whatever his nominal department, without having opportunities of saving life, or of preventing a serious operation, by judicious management of recent hernia. The barbarous old fashion of lifting the patient by his heels and shaking him, that the weight of the bowels might draw in again the part which had escaped, was founded on ignorance or on inattention to the fact, that the weight of the bowels in all positions of the body, is supported by the surrounding parts, and not by the attachments of the bowel.

THAT function sketched in the preceding paragraphs by which the animal body assumes foreign matters from around, and converts them into its own substance, although little inviting in some of its details, is altogether one of the most wonderful subjects which can engage the human attention. It points directly to the curious and yet unanswered question—what is LIFE? The student of nature may analyze with all his art those minute portions of matter called *seeds* and *ova*, which he knows to be the rudiments of future creatures, and the links by which endless generations of living creatures hang to existence, but he cannot disentangle and display apart their mysterious LIFE! that something under the influence of which each little germ in due time swells out, as if to fill an invisible mould of maturity that determines its form and proportions. One such substance thus becomes a beauteous rose-bush; another a noble oak; a third an eagle, a fourth an elephant —yea, in the same way, out of the rude materials of broken seeds and roots, and leaves of plants, and bits of animal flesh, is built up the human frame itself, whether of the active man, combining gracefulness with strength, or of the gentler woman, with beauty around her as light. How passing strange that such should be the origin of the speaking eye whose glance pierces as if the invisible soul were shot with it—of the lips which pour forth sweetest eloquence — of the larynx, which by vibrating, fills the surrounding air with music; and, most wonderful of all, of that mass shut up within the bony fortress of the scull, whose delicate and curious texture is the abode of the soul, with its reason which contemplates, and its sensibility which delights in these and endless other miracles of creation.

PELVIC APPARATUS.

The Secretion of the Kidneys, &c.

Of the large quantity of fluid which is taken into the human body, much escapes with the breath, as is proved by the visible condensation of it in frosty air and on any cold polished surface; part escapes by the skin in perspiration; but the greatest part, after having answered the purposes of the constitution, is separated from the blood by the two secreting organs, called the kidneys, and is thence carried off, holding in solution, various other matters which the system does not require. The kidneys are situated in the loins on each side of the spine; the constant drain of liquid from them passes down by two membranous canals called *ureters* to the bladder, from which the liquid is again expelled through the urethra at considerable intervals according to the rapidity of accumulation.

The bladder is a curious membranous and muscular reservoir, of which the fibres can contract so as to expel the last drop, or can yield to admit a quart.

The passage of fluid downwards through the ureters from the kidney to the bladder resembles the passage of blood in the veins. Authors have erroneously supposed that the weight of the urine suffices to cause its descent, but the bladder and ureters are enclosed in a common cavity with the intestinal canal; and while this is full of a semi-fluid mass of greater specific gravity than the urine, the latter is not only supported by the surrounding pressure, as water would be supported by water, but is pushed upwards or resisted, as oil would be in water: in descending therefore it obeys some other force than gravity.

The *ureters*, *bladder*, and *urethra* are the seats of some of the most distressing diseases to which the human frame is liable. Two classes of these being relievable chiefly by mechanical means, require to be shortly considered here. These are *obstructions in the urethra*, and *concretions*, or *stones*, as they are called, *in the bladder*.

Obstructions in the urethra are generally consequences of an inflammation, which has destroyed the dilatability of a part of the canal. They appear as if a thread or a bit of tape were tied round it, so as to narrow its calibre. Constant irritation—often destroying the general health, fits of fever, broken rest, and even death from total suppression, have been common consequences of this deplorable disease.

Until within a recent period the treatment of such obstructions was pursued very generally according to a blind routine. They were attempted either to be bored open by wedges, called bougies, often of doubtful and tedious operation, or to be destroyed by caustic passed down to them in the end of a bougie, which caustic often hurt the anterior part of the canal, or eat out false passages about the stricture, or opened blood-vessels and caused dangerous hemorrhage.

Struck by the defective state of this branch of the healing art, the author had bestowed considerable attention upon it during the years of practice which he spent abroad, and he then contrived and tried several new means of relief. These were afterwards brought more extensively into use and improved, and others were added, by his brother Dr. James Arnott, superintendant surgeon in the service of the Hon. East-India Company, who gave a minute account of them in a treatise on urethral diseases, and a supplement published in the years 1818 and 1820. They have become perhaps still better known in France than in England, through the work of Dr. Ducamp which described them, and which having been submitted to the French Institute, and most favourably reported upon by the appointed examiners, soon became a standard treatise; in France also, the philosophy of mechanics has been more studied than generally by English surgeons. It is painful to be obliged to add here, that Dr. Ducamp concealed the fact, as regarded these instruments and the views of disease and treatment which suggested them, of his being only a translator. The imposition was not discovered at the time of his death, which happened two years afterwards, hastened apparently by the fatigues of practice which the report of the Academy brought upon him. The author has had so much pleasing intercourse with enlightened and honourable Frenchmen, that he grieves to have this fact to relate.

The objects aimed at by the *new means* were, to ascertain the exact condition of the diseased canal—to facilitate the passing of instruments in cases of difficulty—and to effect a permanent cure. The following *seven* means may be particularized.

1st. *An examining sound:* being a bougie with the point formed of a softer tenacious material, in which fibres of cotton or silk are mixed to prevent any portion from being broken off or detached during use. This sound pressed against the obstruction takes a correct impression of its anterior face, and shews the magnitude and exact position of the remaining opening.

2d. *An expanding or dilator sound*, which is a small tube with a dilatable button at its extremity. The button consists of a little bag, empty while it is passing through the structure, and filled with fluid when it has reached beyond. It readily discovers any other strictures beyond the first, and the state of each.

3d. *A conducting canula* or tube, open at both ends. It is passed down to the stricture, for the purpose of supporting and directing small bougies seeking entrance through very narrow strictures, or of guarding the caustic bougie in its approach to the place of its action.

4th. In cases where the attempt to open the passage has failed by all common means, a conducting tube is first introduced, and through it six or more small bougies are then passed side by side, so as to probe the whole face of the stricture at the same time. It is thus scarcely possible that the opening should not be found.

5th. Were even this means to fail, the conducting tube may be filled with water, under any degree of pressure, which water will either open the passage for the small bougies, or will itself act as the sharpest and most insinuating of all instruments. The stricture by whichever means opened, will then allow the urine to escape. As patients might fear that water forced towards a bladder already too full would only increase the evil, J. Arnott waited for more numerous proofs of the utility and safety of the practice, before strongly recommending it: Dr. Amussat of Paris has lately published a statement of numerous cases of retention thus relieved.

6th. *A dilator* for widening the stricture, after a small instrument can be passed through it: it is intended as a substitute for the *bougies* and *sounds* of former times. The chief objections to these are, the painful friction, the danger of making false passages, the tediousness and imperfection of the cure, and that they cannot dilate any part of the canal beyond the size of its orifice, which during health is the narrowest part of it.

The dilator consists of a tube of thin membrane introduced empty into the stricture, on a ball-pointed wire, and then filled with fluid by a syringe, so as to dilate with any degree of force, from the mere filling of the part to the strain of the hydrostatic press, which will tear the strongest texture that disease can form. The dilating tube is about two inches long, and its near end is fixed to the point of a small catheter, through which the distending fluid is injected. The tube is formed of thin silk riband of various sizes with the edges joined. It is lined with prepared gut of the cat or dog, which is almost as thin as gold-beaters' skin, although very strong and water-tight, and it is covered with the same to give the smoothest and softest possible external surface. When complete and enclosing the blunt wire, it is less bulky than the bougie which would be required for the same case. Thus, it passes easily; it cannot tear the canal or make false passages; it can enter through a small orifice and dilate beyond to any desired extent; and its greatest advantage is, that by opening so as to follow the yielding of the stricture, it can effect at one application, what only a succession of hard bougies with long treatment could accomplish. In one day it has often removed disease, which had resisted other means for months or even years.

Some practitioners and critics, not understanding the law of fluid pressure (explained at p. 229) objected at first to the dilator, that a little water or air pressed into it by a syringe, would be unable to overcome much resistance. Had they seen the instrument lifting so readily as it does a heavy weight laid upon it, or snapping a strong ligature tied round it, they would not have had the prejudice. It was objected also that the instrument would do mischief in urethral disease, by dilating the canal before and behind the stricture more than the stricture itself; now its dimensions being fixed owing to its silken tunic, it never can *distend* beyond the diameter chosen, and therefore, if of the proper size, it can only *press* on the stricture itself. It was also said, that this instrument requires, in the operator, greater manual dexterity and acquaintance with mechanical philosophy than many surgeons possess; but this is merely saying that the arts are progressive, and that the accomplished surgeon of the present day is more dexterous and intelligent than his predecessors of a century ago. It is no reason why the delicate apparatus of the oculist should fall into disuse, that all surgeons are not able to apply it.

Some attempts had before been made to construct a *dilator of fluid pressure*, but they produced nothing of value. For urethral purposes, a simple gut or intestine is worse than useless, for being yielding in its texture, the surgeon can never know truly the size of his instrument, and therefore may do much mischief with it. Dr. Ducamp, in speaking of the dilator, allows that he did not first invent it, but then from ignorance of what constitutes its true value, he takes praise to himself for simplifying and improving it, by throwing away the silk, and using the gut only.—A variety of metallic dilators have been contrived and used by English surgeons since the publication of *Arnott's Treatise on Strictures*, but although manageable with less trouble than the fluid dilator, they want its chief merits.

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from its extremity; and the bougie
passed down to the stricture through

conductor, the point passes beyond the stricture, and carries the caustic to the very spot where it is desired to act.*

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* Dr. Ducamp incurred a singular risk in giving himself out as the first proposer of the instruments and practice described above; for he was already known as a translator of English medical books, and the *Treatise on Strictures* of J. Arnott had been held up to public attention two years before by the various medical reviews, in terms such as the following. "We have carefully perused this little volume, and are of opinion that it is by far the best systematic work on the subject in the English language. It is a judicious compilation, interwoven with much original and acute observation; and it gives publicity to instruments which promise to be of essential benefit to operative surgery."—*Medico-chirurgical Review, January* 1819.

Perhaps Ducamp imagined that the slight alterations proposed by him in the construction of three of the new instruments might be a shield to him when detected; but as the true merit was in the analysis of the subject which suggested such instruments, and not in the mere mechanical fulfilment of intentions, even a considerable improvement on the instruments would have deserved comparatively little praise. Ducamp's changes were trifling or retrograde. His metallic *dilating sound*, is less perfect than metallic sounds contrived by J. A., but not described, because the fluid dilator was found to be preferable. His *porte-caustique* is defective in not distending the stricture at the moment of applying the caustic; and his proposal to make a *dilator* without the silken tunic, renders it not only an useless, but a dangerous instrument; indeed such as obliged him to use the caustic in almost every case. His silence with respect to the *liquid probe*, favours the conclusion, that he did not understand it, although Dr. Amussat of Paris has since used it with such success:—and the same remark applies to the *double catheter* or *sonde a double courrent* (see Arnott's cases), which Dr. Jules Cloquet, of Paris, has lately been applying with so much zeal."

The following are extracts from the report made by the commissioners of the French Institute, Doctors Deschamps and Percy, in May 1822, on the subject of Ducamp's work, entitled *Traité des retentions d'urine*.

Stone in the bladder, is another disease relievable chiefly by mechanical means.

The urine, as secreted in the kidneys, contains dissolved in it, a variety of substances, which,

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"This treatise concerning a most important malady, because one of the most common and painful which affects humanity, has appeared to us to merit more than ordinary attention.

"When, some years ago, your same commissioners had to express their opinion of another work on this subject, they commended the zeal and industry of its estimable author (Dr. Petit), but they could not conceal that there were still imperfections in his modes of treatment; and also that they were almost entirely either borrowed or imitated from the English.

"The work of Dr. Ducamp now leaves us, however, nothing more to desire, and we have no longer reason as regards this subject, to envy our neighbours. Although a volume of moderate size, it is incomparably more complete and full of matter than the bulky treatises lately published in other countries. * * * Ducamp leaves all these authors far behind him, whether as to the soundness of his doctrines, the superiority of his trials, or the invention of instruments.

"He takes a print or model of the stricture by an instrument of his invention, called *Sonde Exploratrice*. (Arnott's examining sound, page 388.)

"For introducing bougies in difficult cases, he uses an elastic gum tube, which he calls *conducteur*. (*Described above, page* 388.)

"Mr. D. has invented for measuring the length of strictures, &c., an instrument which when introduced, enlarges beyond the stricture. (*The dilating sound, page* 588.)

"The nitrate of silver, or common caustic, is what he uses for destroying strictures, but he employs it in a new manner, which appears so as to give it new powers, and to deprive it of all its former dangers. * * He carries the caustic into the stricture by means of his *porte caustique*. (*See above, page* 388, No. 7, of Mr. Arnott.)

" . . . To enlarge the canal at the morbid part to its true calibre, he uses an instrument which he names a *dilatateur*.

under certain circumstances, separate and assume the solid form, as sugar separates in small crystals from cooling syrup, or salt from cooling brine:—and it is thus that those minute grains are produced, which we call *urinary gravel.* A single particle of gravel remaining by any accident in the bladder, soon attracts to itself more matter of the same kind, and becomes the nucleus or centre of an increasing mass, which is the *stone in the bladder.*

In a second Tract by the author's brother, published in 1820,* the following paragraph appears:

"From the severe suffering of the patient, labouring under stone in the bladder, and the remedy being an operation so painful and dangerous, that many wear out their lives in certain misery, rather than submit to it; it has arisen, that no part of surgery has excited more attention,

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(*Dilator*, page 589). He does not conceal that this instrument had been imagined before him, but he has the merit of perfecting it, and of reducing to practice what before had only existed as a project.

"......In rendering justice to the able men who have preceeded Ducamp, we must still say that no one has displayed so much industry, dexterity, and talent, and we think that he has high claims to the confidence of patients and the gratitude of the profession, and that his work merits the eulogium of the Academy.

(Signed) DESCHAMPS,—PERCY, Reporters.
CUVIER, ... Secretary.

* Cases illustrative of the treatment of urethral obstructions and of stone.—By James Arnott.—Longman and Co., 1820.

either in the medical profession, or out of it.* No very important change in the treatment of this disease has now been made for upwards of a century; and, indeed, it has appeared to be the opinion of modern surgeons, that the manner of operating practised by Cheselden, about a century ago, and which has been called the "glory of English surgery," was so nearly perfect, as to leave little room for improvement. The hopes which the rapid progress of chemistry, and the grand discoveries relating to stone, of Scheele, Wollaston, Fourcroy, and others, some time ago gave birth to, that we should be able to dissolve stone by lithontriptics, and thus save the horrors of lithotomy, had again died away, and the researches of many ingenious men who have been and still are employed about the question, have for their end, more to prevent the formation of stone by remedies and regimen, than to improve the manner of removing it when once formed. I trust, however, notwithstanding the supposed exhausted nature of the subject, that the following essay will prove that much was still possible in the improvement of this department of the healing art."

The publication from which the above paragraph is taken, and the "*Treatise*" which preceded it, in both of which new instruments and new processes were described, and interesting facts were detailed, powerfully roused the public attention in England to the possibility of improving the treatment of stone; and about the same time, a similar spirit awoke independently in France. The results of the consequent investigations are likely to be of great importance to humanity. In the medical publications since that time, numerous cases are recorded of lithotomy superseded by new means. We shall now give a brief account of the principal means, intended, however, only to interest the reader in a manner that may lead him to the perusal of the original works, where more minute information is to be found.

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* The Catalogue of authors who have written upon stone, occupies in Plouquet's *Literatura Medica*, no less than twenty-nine very closely printed quarto pages.

1st. The *dilator*, as applied to the treatment of stone, has already been spoken of in the preceding pages.

2d. The *double catheter*. This instrument, and the purposes to which it is applicable, are described in *Arnott's Cases*. It has two channels, by one of which fluid may pass into the bladder, while by the other there may be a returning current mixed with urine. It is equipped with two pliant tubes, of which one leads to the *supplying reservoir*, and the other to the *waste vessel*. It will soothe irritation of the bladder, whether arising from stone or not, by keeping the acrid urine in a diluted state, or by applying bland and medicated liquids directly to the internal surface of the bladder. Not being larger than a common catheter, it may be worn for any period as the common catheter now is. It need prevent no sedentary occupation, and may be used during sleep. It will act powerfully to dilate a contracted bladder, on placing the reservoir high, and letting the fluid distend with the pressure of a lofty column. It also affords by far the best means of admitting any solvent of stone to the bladder. Even pure water is a solvent of most animal calculi, as is proved by placing them in a running stream; but the living bladder bears with impunity any diluted acid or alkali.

2d. *The syphon catheter* (also first described in *Arnott's Cases*) is merely a catheter of a length that will allow its external part to descend, so as to constitute the long leg of a syphon. (*See Pneumatics.*) Its extremity is turned up a little, or has a portion of soft animal gut tied upon it to act as a valve, for preventing the entrance of air. The most useful application of this instrument, is to keep the bladder empty after operations, until the healing process has made a certain advance. The diffusion of urine among the surrounding parts after lithotomy, is often a cause of death; and the syphon catheter, by providing a channel which the urine must immediately obey, obviates the danger. This instrument is sometimes useful in very irritable bladders, by carrying off the urine as it descends, and thus preventing the distension of the bladder and the excruciating contractions.

3d. A *forceps*, calculated to pass through a tube into the bladder, and to open there, for the purpose of seizing any small stone or other solid object offered to it, was described long ago in the *Armamentum Chirurgicum* of Scultetus, but was again forgotten until John Hunter's investigations led him to a second invention of it. Such an instrument has now for a considerable time passed under the appellation of *Hunter's urethra or bladder forceps.* It answers well for extracting small stones, and therefore, if used in time, may generally prevent the necessity of lithotomy.

But a new and intense interest has lately been excited with respect to the forceps, as a means of removing stone, by the discovery—also an old discovery revived—that a *straight* tube may be passed to the bladder as a conductor, instead of the *bent* tubes or catheters commonly used. A door is thus, as it were, opened directly into the bladder, through which a stone may even be seen, if desired, and may be easily caught and broken to pieces, and brought away without the slightest injury to the living parts. Dr. Civiale, of Paris, has the merit of first contriving good instruments for this operation, and of having performed it already with complete success in many cases. He introduces a strong forceps, which seizes and holds fast the stone; and with a drill which passes through the handle of the forceps, and is turned rapidly by a drill-bow acting on its external end, he bores and breaks down the stone, of whatever size, until no piece remains so bulky as not readily to escape through the open tube.

Dr. Darwin, in his *Zoonomia*, published in 1790, proposed to seize stones by forceps passed into the bladder, and then to break them down or destroy them mechanically; but the supposed necessity of working through a long bent tube prevented trials from being made. The author also shewed some years ago (see *Cases*, page 93), that it was possible to pass a bag into the living bladder, so as to enclose a stone there, and that any solvent might then be injected into the bag, and again withdrawn without coming into contact with the bladder. This was shewn rather to excite attention to the possibility of operating in the bladder with great precision, than to recommend such solution as a means of destroying stone.

Several very ingenious instruments for breaking down the stone, have been contrived by other persons since that of Dr. Civiale, but there is still the objection to all, that the stone is broken into such fragments, that many of them require again to be treated as distinct stones, and thus the painful operation has to be repeated many times.—The author deems it possible to make a forceps of many claws or ribs which should surround the stone so loosely as to leave it freedom of motion, like a loose kernel in a shell, and so that on making the forceps itself whirl backwards and forwards, like the drill in Civiale's apparatus, the stone might be quickly rubbed to dust by the friction or file-action of the roughened interior of the claws on its outer surface. The bladder might be filled during the operation with water, or even air, to secure plenty of room for the turning instrument; or a slender external forceps or guard might be used to prevent contact of the bladder with the moving instrument. Out of the body, a stone harder than urinary calculus, placed in a cage with rough interior, and made to whirl as described, is soon reduced to dust. There are various ways of making a forceps or cage for this operation, which will readily suggest themselves to any person knowing what has already heen done in the department, and having the ingenuity likely to engage him in such a pursuit.

The *high operation* of lithotomy possesses over the common *lateral operation* such advantages as the following;—thinness of the parts cut through —distance of the knife from important arteries—stones of very large size may be more easily extracted—the prostate gland is not wounded.—But it has not become general, because—there was difficulty of avoiding the peritoneum while making the opening into the bladder—there was danger of effusion of urine among the cut parts, after the operation—and where the bladder was contracted, the incision had to be very deep. Now the *double catheter* will dilate the contracted bladder, the *syphon catheter* will prevent the effusion of urine, and the jointed *sliding sound* (see *Cases*, page 104) will ensure the accurate cutting in the desired place. Had there been no less hazardous means, therefore, than cutting, the high operation with the new securities might have been the best.

When a catheter has to be retained in the bladder after any operation, and where, if it slipped out, it might be with difficulty replaced, something should be passed through it like a small spring forceps, to expand and become a sort of button within preventing its escape (see *Cases*, page 103).

UTERINE PHENOMENA.

Although so many of the uterine phenomena are mechanical, there are few of them that could be treated of with advantage, except in connexion with particulars, of which the consideration does not belong to a work like this. As mere examples of uterine physics, we shall cite the following: 1st. The protection given to the tender fœtus by the *liquor amnii* in which it floats. A blow on any part of the parent cannot reach the fœtus, but is expended on the surrounding water. 2d. The head of the child, because ossification begins in it first, is of greater specific gravity than the other parts of the body, and therefore generally lies at the bottom of its liquid bed. It is thus ready to appear first in parturition, according to the safest course of delivery. 3d. The membranes distended by the liquor amnii descend before the head, as a soft but powerful wedge preparing the way. 4th. We have already spoken, at page 311, under the name of *pneumatic tractor*, of a circular piece of leather, or similar soft substance, kept extended by an included solid ring or otherwise, to be used in certain cases as a substitute for the forceps. The forceps, to be well and safely used, requires address, which even the naturally dexterous man cannot possess without a certain degree of continued practical familiarity with it; and except in large towns, a man must be unfortunate in his practice who often requires it: hence the really small number of persons who use it well. The author proposes to publish on this matter, and on some other strictly professional subjects which are lightly touched upon in the present general work, such a practical detail, as for the dilator, syphon, catheter, &c. is found in his brother's *Treatise and Cases*.

Conclusion.

It is almost superfluous to remark here, that for the practice of general and obstetric surgery, learning and judgment are of little avail, unless accompanied by mechanical dexterity: and it is one of the improvements yet to be made in our systems of education for various professions, to cultivate more methodically the use of the hands. Children and young people, in obtaining practical familiarity with ingenious toys, tools of carpentry, games of address, musical instruments, &c., are often fitting themselves for the important business of their future life.

While the author directs the attention of the profession to the important physical considerations set forth in the preceding pages, he deems it necessary most pointedly to remark, that in the living body mechanical principles are associated in their operation with the more recondite principles of chemistry and of life; and that the man who allows his mind to dwell too exclusively on any one of the three classes, must be a very bad reasoner in questions either of health or disease. It is within a very recent period, however, that just views on this subject have begun to prevail, and that the titles of the peculiarly mechanical physician, or chemical physician, or physician attending only to the influence of life, are likely to be no longer justly applicable. The bright beams of true philosophy are at last breaking in upon the very complex and difficult subjects of medical inquiry; and where formerly keen penetration beheld only confusion, even common minds now begin to see clear divisions and beautiful arrangement.

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THE END.

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SUPPLEMENT

TO THE

FIRST EDITION

OF

DR. ARNOTT'S

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OR

NATURAL PHILOSOPHY;

And in which the few Paragraphs added to the Work since the
SECOND EDITION *are distinguished by asterisks* *,
and the page of the second edition to
which they belong.

LONDON:
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1828.

N.B. Persons who procure this supplement, are requested at once to make notes of reference to its paragraphs, in the several pages of the volume to which the paragraphs belong. The early edition will then, as to matter of fact or substance, be nearly on a par with the third, although not perhaps as to clearness of style and simplicity of explanation. The first edition issued from the press less complete than might have been, because the author's experience of such business began with it, and because when he had once determined to publish the volume, although his professional duties left him little more than portions of the nights to devote to it, several reasons urged him to do it quickly. He hopes that his second volume, now in progress, will not stand in need of similar apologies.

The first edition is complete for non-professional readers, when the section from page 585 (second edition from page 609) to the end is omitted. The binder will take directions accordingly.

7th June, 1828.

LONDON:
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PREFACE

TO THE SECOND EDITION.

ALTHOUGH paradoxical, it is true, that human knowledge, the more it is accumulated and perfected, is also the more easily acquired and recollected. As an instance we may refer to our present knowledge of the celestial motions. These, to our ancestors, appeared so inexplicable, that to observe and analyze them, some of the most gifted individuals devoted their lives—yet when at last contemplated through the records of many centuries, by the penetrating genius of NEWTON, they were found all to range themselves under a few simple expressions, easily intelligible and easily remembered by an ordinary mind. Thus, now, not only is the confusion of past times, in regard to astronomy, converted into a scene of beautiful simplicity and harmony, but we are able to predict, with certainty, many of the changes which are to happen in time to come. Facts of this kind make it appear, that the progress which is still to be looked for in the human sciences, instead of threatening men who require a good education with additional labour, promises to convert their necessary labour almost into amusement,—amusement, however, which will lead to the most important results.

The author has thought it necessary to make this observation to meet what has been stated by not a few against his present volume, namely, that it is so simple, or easily understood, that he must have left untouched many of the important principles of natural philosophy, lest the study of them should prove too difficult for the generality of his readers. Now the fact is, that he has not only included all the general truths belonging to the department of Physics, but has introduced many matters which are not usually found in treatises on the subject:—what he has avoided are matters of inferior, or at least of limited interest. He has, however, availed himself of a circumstance, either not known or not adverted to by former writers, *viz.* that what may be called the *mathematics of common sense or experience*, and which may be expressed in ordinary language—as distinguished from *technical mathematics*, which has its peculiar language, is perfectly sufficient for the explanation of all the great laws of nature. By attending to this truth, and aiming at extreme simplicity of arrangement, he has avoided that abtruse phraseology which is so generally repulsive, and he hopes he has facilitated to many gifted individuals, who would otherwise have been deterred by the idea of difficulty, the study of that one among the four great departments of human science, which, after the department of mind, is the most pleasing in its nature, has attained the highest degree of perfection, is the most fruitful of valuable applications, and when fairly understood in its relation to the others, establishes a lucid order through the whole of the intellectual acquirements.

Astronomy, which is the instance chosen above, is only one of innumerable subjects, which, when imperfectly understood, appear obscure and difficult, but when more fully investigated, become simplicity itself. As an example from the studies of medical men may be mentioned the question of the movement of the blood in the veins, which has lately been discussed in medical societies and reviews with considerable earnestness. In this question, the appeal is necessarily made to the laws of Natural Philosophy, which govern the phenomenon; but because the study of these has been little cultivated by the faculty, more time has been absorbed in futile disputation and experiment than would have sufficed for acquiring a competent knowledge of the whole body of Physics:—now the single section of Physics, which bears on the point, if understood in a moderate degree, would have caused all the difficulties at once to vanish. The circulation of the blood, again, is but one of numerous and scarcely less important subjects in the medical art, to which Natural Philosophy is the easy and only key.

These last reflections are intended as a reply to a second remark which has been made in some quarters with respect to the present volume, *viz.* that its subject is not of primary importance in medical education. Although no one who had advanced beyond the mere threshold of the study could have held this opinion, the author finds it necessary to advert to it. His labour in preparing the present volume will have been vain, if by it he prove not to his readers that the magnificent fabric of human knowledge has Physics or Natural Philosophy for its foundation; Chemistry for the second department, resting on the first; Physiology, or the doctrine of organic Life, for the third, resting on the other two, and fully intelligible only to the mind familiar with the others; while the science of Mind crowns the whole.

The Author had hoped to be able to publish in the course of this autumn the remaining portion of his Elements of Physics, but the early call for this second edition has prevented him. As the part in question, however, has long been written, there is nothing required in regard to it but what he thinks his leisure will permit him soon to accomplish.

The Author might be accounted insensible to the approbation of his own profession and of society in general, if he allowed the present occasion to pass without alluding to the reception which his book has met. Gratifying indeed has it been to him, and encouraging to the completion of his task. With the desire of making the present volume as worthy as he could make it, of the approval of those into whose hands it may fall, he has carefully revised it: but as he had previously well considered the subjects, he has found nothing beyond verbal inaccuracies to correct. He has however been able to simplify some of his illustrations, and has here and there added new matter. Whatever of this is of a nature to appear complete in a detached form, will be printed separately for the accommodation of those who have so recently procured the first edition.

It has been mentioned as a fault in the former edition, that no separate enumeration any where appeared of what might be considered novelties in the work. Now many of these are rather in method, condensation, illustration, &c., than in particular subjects. The following, however, may be examined as insulated specimens of new disquisition or suggestion:

Theory of the Spinning-Top	Page 65
Peculiar Pulley	160
Distorted Spine	198
Swimming and Diving	273, 298
Transference of Heat in Liquids, Warm Bath, Brewing Refrigeratories, &c.	282
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Water-Wheels for Ships	417
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Analysis of Articulate Speech and Treatment of Stammering ....Page 556
Substitutes for Stomach-Pump, &c. 579
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Means of Treatment for Stone 594

30*th Nov.* 1827.

At page xviii, *after "revelation," line 5th from bottom.*

And all his arts are founded on this knowledge—some of them on the single part of Physics, as that of the machinist, architect, mariner, carpenter, &c.; some on Chemistry, which includes Physics, as that of the miner, glassmaker, dyer, brewer, &c.; and some on Physiology, which includes all the rest, as that of the scientific gardener or botanist, agriculturist, zoologist, &c. The business of teachers of all kinds, and of governors, advocates, linguists, &c. &c., respects chiefly the science of mind.

At page xx, *after line 4th from bottom.*

The most complete education as regards mind, can only consist in an acquaintance with *Natural History* and *Science*, and with the signs of ideas, *viz. language*, in one or more of its idioms, and the *visible signs* of letters, cyphers, &c. for representing words. As regards the body, it consists in the formation of various habits of muscular action, as in gymnastic exercises, dancing, riding, in performance on musical instruments, games of address, drawing and painting, use of fire-arms, and other exercises of utility or amusement. By reviewing a table of such matters, each man may see at once what he can know, and what it may suit his particular condition to study.

At page xxii, *after* "*mind,*" *line* 21*st from top.*

The reason for bestowing much attention on the Greek and Roman languages was good some centuries ago, because then no book of value existed which was not written in one of these languages; but now the case is completely reversed, for he who learns almost any matter of science from old books is learning error, or at the least, knowledge far short of modern erudition. As to the higher mathematics, again, while they merit great honour, as being the instrument by which many useful discoveries have been made, and the conjectures of powerful minds have been confirmed, still a very deep investigation of them is neither possible to the generality of men, nor if it were so, would it be of any utility.

At page xxiii, *after* "*men,*" *line* 15*th from bottom.*

And even then, the book of nature cannot be compiled, as many encyclopedias have been, by each individual writer taking a distinct part or parts; but by the parts being undertaken conjointly by several, so that he who conceives most happily for students may sketch, he who is learned may amplify and complete, he who is correct may purge, he who is tasteful may beautify, &c. After such a book existed, it would not become the object of talented individuals to write a *new book*—which again would necessarily have the imperfections of an individual attempt—but to assist, under the direction of a superintending council, in perfecting the existing work. The composition of the *Book of Nature* might be a worthy object of rivalry even between nations.

At page 52, *after line* 10*th from bottom.*

The actions of beating a coat or carpet with a cane, to expel the dust; of shaking the snow from one's shoes, by kicking against the door-post; of knocking a dusty book against a table, or shutting it violently—all illustrate the same principle.

At page 66, *after line* 4*th* (* *p.* 63).

It thus appears that the very fact of a spinning-top inclining, causes the point to shift its place, and so that it cannot rest until it come again directly under the centre of the top. It is remarkable that even in philosophical treatises of authority the standing of a top is still vaguely attributed to *centrifugal force.* Hence some persons believe, that a top spinning in a weighing scale, would be found lighter than when at rest ; and many most erroneously hold that the centrifugal force of the whirling, which of course acts directly away from the axis, and quite equally in all directions, when the top inclines, becomes greater upwards than downwards, so as to counteract the gravity of the top. The way in which centrifugal force really helps to maintain the spinning of a top is, that when the body inclines or begins to fall in one direction, the motion in that direction continues until the point in describing its curve has forced itself under the body again.

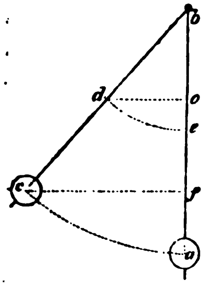
At page 79, *after* "*increases,*" *line* 21*st.*

This truth is well exemplified by the pouring out of molasses or thick syrup : if the height of the fall be considerable, the bulky mass, which first escapes, is reduced, before it reaches the bottom, to a small thread; but the thread is moving with proportionate speed, for it fills the receiving vessel with singular rapidity.

At page 82, *after line* 6*th.*

It is shewn in a preceding paragraph, that a body falls four times as far in two seconds as in one, although the velocity at the end of two seconds is only doubled. For the same reason, a body shot upwards with double velocity, rises four times as far as if shot with a single velocity; if with triple velocity, it rises nine times as far, and so forth.

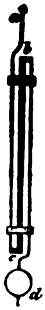
At page 84, *after* "*If,*" *line* 4*th from bottom.*



If a pendulum *b a* be twice as long as another *b e*, it has twice as much to fall in its descending arc *c a*, as the other in its arc *d e*, while in corresponding parts of the two paths, the slope or inclination is always equal.

At page 85, *after line* 14*th.*

To counteract the dilatation or contraction of pendulums from the changing heat of the seasons, various ingenious contrivances have arisen. One of the best of these is the *gridiron pendulum*, as it is called, from consisting of various rods of metal. It renders the different dilatability by heat of two metals composing it, the cause of unchanged length in the whole. The adjoining sketch may shew that if the central rod of brass (here represented by a *strong* line from *b* to *c*) dilate just as much as the two rods of steel on either side of it do together (the expansion of brass by heat being about double that of steel), it will exactly counteract the lengthening of these, and will keep the ball *d* always at the same distance from the point of suspension *a*.



At page 87, *after line* 12*th.*

As the rate of a clock is influenced by the length of its pendulum, so is the rate of a watch by the size or diameter of its balance-wheel; and heat which retards the motion of a common clock, by lengthening the pendulum, retards the motion of a common watch by dilating the balance-wheel. Man's ingenuity however has found a remedy for the latter case as for the former, *viz.* the contrivance called the *expansion balance-wheel.* Of this the circumference, instead of being a continuous ring, is made up of two half-rings, each attached by one end only, to a cross bar, and which half-rings being of brass on the outside and of steel within, bend or curl inwards by heat—as a sheet of damp paper bends when held to the fire—and thus diminish the size of the wheel at their loose extremities, so as just to counterbalance its increase by the expansion of the cross bar.

As the motion of a pendulum has relation to the *force of gravity*, so has the motion of the balance-wheel to the *stiffness of the balance-spring;* and the regulator of a watch is merely a pin which bears against the balance-spring, and which, by sliding backwards or forwards, so as to shorten or lengthen the part of the spring left free to bend, changes the degree of its stiffness.

At page 104, *after* "*it*," *line* 16*th.*

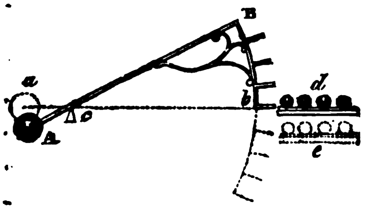
The ascent of a sky-rocket is aided also by the recoil of the rocket from the part of its substance, which is constantly being shot downwards.

At page 105, *line* 6*th from bottom.*

When a billiard-ball strikes directly another ball of equal size, it stops, and the second ball proceeds with the whole velocity which the first had:—the action which imparts the new motion here being equal to the re-action which destroys the old. Although the transference of motion, in such a case, seems to be instantaneous, the change is really progressive, and is as follows. The approaching ball, at a certain point of time, has just given half of its motion to the other equal ball, and if both were of soft clay, they would then proceed together with half the original velocity; but, as they are elastic, the touching parts at the moment supposed, are compressed like a spring between the balls, and by then expanding, and exerting force equally both ways, they double the velocity of the foremost ball, and destroy altogether the motion in the other.

At page 133, *before last line* (* *p.* 136).

Another case of the lever, exhibited in the adjoining diagram, serves well to explain the nature of *mechanical powers* in general. Suppose A to be a weight of four pounds at the end of the rod or lever A B, turning on C as its axis, or fulcrum, and having the arm C B four times as long as the arm CA: one pound at the end B, would balance the four pounds at the end A (the weight of the lever itself is not regarded here), and with the slightest additional weight would preponderate. Now let us suppose the arc B *b* fixed to the long arm of the lever, and having four projections or shelves from it, on which balls of one pound might rest: if one of the four balls from the plane *d* were to roll upon the first shelf, with one grain more, it would lift A, and would itself descend to plane *e*, one inch below; then a second ball of one pound would occupy the second shelf, and would descend in the same way, and then a third, and then a fourth; and when the whole four had fallen from *d* to *e*, they would just have lifted the four pound weight, at the other end of the lever, one inch. Then, although one pound were seen here lifting four pounds, it would only lift it one-fourth part as far as it fell itself, and the sum of the phenomenon, when ended would be, that four pounds, by falling one inch at the long end of the lever, would have lifted four pounds one inch at the short end. No *mechanical power* or *machine* generates force more than the lever in this case.



At page 134, *after last line* (* *p.* 137).

We must warn the reader, however, that there are many important considerations connected with the practical employment of forces, according to their respective nature, and that of the resistance to be overcome, which cannot be entered upon in this elementary work. In very many cases there is a great waste or unavoidable loss of force, because the resistance in yielding runs away or escapes from the force, as when a ship runs away from the wind which is driving her, or the floats of a quick moving water-wheel from the stream which turns it. Horses drawing boats or carriages at the rate of five miles an hour, may exert great force; but with a speed beyond twelve miles, nearly their whole effort is required to move their own bodies. As a general rule, although *equal quantities* of force balance each other when applied to parts of a lever or wheel altogether or nearly at rest, still when force is made to act near an axis or fulcrum, to produce considerable velocity in a more distant part, much of it is wasted in pressure against the fixed fulcrum.

At page 143, *after line* 20*th.*

A projecting rod or plank or branch of a tree, with a scale attached to it, might thus be made to answer the purpose of a weighing-beam, by observing minutely how far a certain substance, attached to it, bent it, and then trying what weights would bend it as much.

At page 175, *after line* 4*th.*

It is true also, that a small wheel will sink to the bottom of a hole, where a larger one would rest on the edges as a bridge. It is not true, however, according to the popular prejudice, that the large hind-wheels of coaches and waggons help to push on the little wheels before them: fore-wheels are made smaller, merely to facilitate the turning of the carriage.

At page 176, *line* 10*th from bottom*(* *p.* 178).

When wheels, instead of standing upright, like *a* and *c* shewn here, are made to incline outwards, as is common, owing to the ends of the axle-tree being bent down a little, to give a security against the accident of the wheels falling off, the pull to the horses in deep or sandy roads is much increased; for an inclining wheel naturally describes a curved path, as is seen when a hoop or wheel-barrow inclines; and the horses, in drawing straight forward, therefore, have to overcome this deviating tendency in all the wheels. This source of resistance is still more remarkable when the inclined wheels have broad rims. Such wheels must be of smaller diameter at the outer than at the inner edge, as the end of a cask is smaller than its middle; then, as the iron hoops or tires which cover the different parts cannot all truly measure the same length of road by an equal number of turns, there will be a constant rubbing or grinding forward of the lesser rings, and a grinding backward of the larger, which must injure the road, rapidly wear the iron, and exhaust the strength of the pulling animals. Such wheels rolling free would describe a circle, as is seen when a thimble or drinking glass or sugar-loaf is pushed forward on any plane surface.

At page 177, *after "rail-road," line* 16*th.*

and the conclusion follows, that although the original expense of forming the level line might considerably exceed that of making an ordinary road, still in situations of great traffic the difference would soon be paid for by the savings, and when once paid, the savings would be as profit ever after.

At page 183, *after line* 8*th.*

In the moon, where the weight or gravity of bodies is less than on earth, on account of her smaller size, mountains might be many times higher than on earth—and observation proves that the lunar mountains are in fact much the highest.

At page 217, *after line* 7*th from bottom.*

Note to the Second Edition.

A distinguished member of our profession, who seems often to have contemplated the human frame under the aspect which elevates the thoughts towards the Creator, has lately published, with the title of *Animal Mechanics*, and as a part of the *Library of Useful Knowledge*, an essay on the perfection of design manifested in the animal structure. It has been eulogized in many of the public prints, by friends of the diffusion of knowledge, as one of the most admirable productions of modern times; and in consequence has already been demanded by the public to the extraordinary extent of about thirty thousand copies. On comparing this new essay with the present section of the Elements of Physics, to which it has close relation in title, matter, and arrangement, it will be found to have substituted for the detail of certain of the facts adduced here as striking evidences of creative contrivance, an elaborate exposition, constituting nearly half its substance, of what its author has deemed instances of still more profound design than had hitherto been noticed, and still more striking examples, therefore, of God's wisdom and power. Had these instances appeared to me in the same light, it would have been my agreeable task to have incorporated them with the matter of this second edition: but they do not; yet the wide diffusion of the essay, and the authority with which it has come before the public, make it imperative on me, as a faithful teacher, to notice them here, and to state my opinion, that with respect to every one of them the author has fallen into an extraordinary misapprehension of the true nature of his subject, and has attributed to the Creator contrivance or design which is far from being divine. I publish my remarks without hesitation, as regards either the author, or the public-spirited society of which he is a member, assured of their approval, if the remarks are well-founded; but I feel that I shall be doing a kind of sacrilegious violence to many amiable minds, by undeceiving them as to what they have deemed so excellent. The feeling with which the essay is written so naturally interests good men, and the whole is rendered so plausible by the appearance which runs through it of ultra-minute acquaintance with the subject, that thousands of intelligent persons must have yielded up their judgment to the persuasive writer, and must have studied the work with unmixed delight. These are not reasons, however, for concealing the truth, and certainly there is no need to twist or exaggerate truth, for the purpose of proving from the structure of the human body, the wisdom and benevolence which presided at the creation.

The following are part of the errors alluded to. One at least vitiates each chapter.

CHAP. I.—*On the Head.*

The author, after stating as usual that the skull has the strength and advantages of the arched form, but not aware apparently that there are kinds of arches so distinct from each other, as to have even direct opposition in certain respects of proportion, &c., hopes to prove the singular perfection of design in the skull, by shewing that it has the peculiarities of the architectural arch, or that of bridges, domes, &c.; and he expresses wonder that men should have been so long in learning to build domes, when every individual carried in his head a model planned by the unerring Architect! Now the architectural arch has material, form, proportions, &c. calculated to resist the force of gravity only, which is unceasing, and acting only in one direction, and which moreover is essential to the stability of the arch, for if this come to incline a little from its natural position, or be shaken by an earthquake, it is instantly demolished. On the other hand, there is the arch of a cask, or barrel, egg-shell, or cocoa-nut, &c., in which the tenacity of the material is many times greater than necessary to resist the influence of gravity, and comes in aid therefore of the curve, to resist forces of other kinds, approaching in all directions, as in falls, blows, unequal pressure, &c. Now the skull, which may be called the oviform shell of the brain, with the face and mouth attached to its under side, is truly an arch of the latter kind, and having very much oftener to bear pressure and blows coming upon it laterally, than from above. A thimble, bee-hive, limpet-shell, &c. are much nearer approximations to the dome than the skull is, because, like the dome, they are open in one direction, yet by reason of their smaller size and the tenacity of their material, they are perfect, without the peculiar securities of the dome. What a mistake then was it for our author to suppose himself proving the perfection of the skull, by trying to exhibit in it peculiarities which, had they really existed, would have been just so many faults!

CHAP. II.—*On the Spine.*

Our author holds, that an important analogy exists between the spine and the mast of a ship. Now supposing that there had been some useful lesson obtainable by comparing the crooked, pliant, every where moveable spine, with the straight, rigid, singularly steadied mast, it will perhaps appear that he was not likely to draw it forth, owing to his imperfect acquaintance with naval matters, as proved by the following assumptions, all of which are errors, and yet all are points or parts of his argument:—that the foremast of a ship being very upright, and far forward, causes the vessel to *tack* or *stay* the better—that the main and mizen-masts are made to *rake* or incline backwards, to diminish the danger to them from the forward pitching of the ship—that masts are *sprung* or broken chiefly by coming into contact with the deck when the rigging is too slack:—that certain boats are the fittest of all to withstand storms, because they are without decks, and therefore cannot injure their masts in the way above alluded to. Our author must have been singularly deceived in some way with respect to these matters, as he may learn by applying to any intelligent seafaring man.

CHAP. III.—*On the Chest.*

To prove a hitherto concealed perfection here, he asserts that the elasticity bestowed on the cartilages of the ribs is capable of maintaining respiration, and thereby life, in cases where the respiratory muscles have become too weak to perform their office aright—just as if he were to say, that a spring applied to a pump-handle would continue to lift water, or at least would help, after the worker's arms were tired.

CHAP. IV.—*On the Limbs.*

Having mentioned the admirable fact, first pointed out by Borelli, that when a bird sinks down into the sleeping attitude on the branch of a tree, the bending of the limbs so tightens the sinews of the talons, that the foot grasps the branch firmly without the attention or muscular exertion of the animal; he wonders that a similar fact in the human body should have been so long overlooked, *viz.* that when a standing person changes from the soldier's attitude of *attention* to that of *stand at ease*, the bending of the knee and sinking of the pelvis on one side, lifts the other side of the pelvis so as to tighten a ligament or fascia which passes from it to the knee-pan below, and so keeps the leg straight without the fatigue of muscular exertion. Now this is altogether an error. The true reason why the straightened leg requires no muscular support is, that the knee falls a little behind the general line of the leg, and causes the strain to come upon the posterior ligaments of the joint. And proving that there is no tightened fascia, as assumed, between the pelvis and knee-pan, the latter remains quite loose and moveable—yea, even if the distance between the pelvis and knee-pan be still further increased by bending the knee while standing on the other other leg.

CHAP. V.—*On the Cordage or Tendons.*

In the attempt to prove the tendons to be constructed with consummate skill, he has accumulated many errors. Setting out from the known fact that when a broken rope is spliced, that is to say, has its ends again united by being interwoven with each other, it rarely breaks a second time at the junction; but, not adverting apparently to the circumstance of the rope at that part being double, 1st, he assumes, as a general truth, that plaited ropes are stronger than twisted ropes—contrary to the fact, as is known to every rope-maker; for, what then prevents their plaiting all their ropes instead of twisting them? 2d, He next assumes that the fibres of the tendons are interwoven or plaited, because thereby stronger:—the fact being, however, that they are parallel, although, when torn asunder laterally, a remaining adhesion at a few points may give the appearance of crossing fibres. 3d, He seems not to have been aware that a rope, whether plaited or spliced, will bear much less weight than its constituent fibres loaded singly—the reason being, that in no rope can the tension of the fibres be made so equal that each shall bear its exact share of the load. Plaiting and twisting therefore are defects, and are forced upon men only because the fibres of which ropes are composed are shorter than the ropes, and must be made to cohere, either by being knotted together or by the lateral friction of plaiting or twisting. The chains or wires of a suspension-bridge, which reach from end to end, are neither plaited nor twisted together, which would much weaken them, but are merely secured in parallel contact, as the fibres of long animal tendons also truly are.

The treatise, which we have been obliged thus to criticise, we believe was hastily written, and that the plan was changed more than once in its progress. This will account for its being so little like the valuable other works from the same source.

Note to the Third Edition (* *p.* 223).

I introduced the foregoing note reluctantly, for I knew the treatise examined to be from the pen of Mr. Charles Bell. It would have given me much pleasure to have had rather to speak of his high professional merits, or of some acts of professional charity which at my request he had performed, not less honourably to his generosity than to his skill. I had tried to avoid the necessity, first, by telling him of the errors, with a view to correction in subsequent editions of his work; and afterwards, when during his absence from town it was published without alteration, by representing the matter to a leading member of the *Society for the Diffusion of Useful Knowledge.* This gentleman deemed it necessary for me to publish my note. From the resemblance of the treatise to parts of my work, many persons believed it to be mine, and it was bound up with my volume. I was accordingly blamed for the errors by those who discovered them; or believed to sanction the opinions by those who did not; and by some who knew it to be Mr. Bell's, and believed it faultless, the differences between it and mine were thought defects in mine. By allowing it then to remain uncorrected and unnoticed, I should have allowed error extensively to prevail on subjects which I professed to explain, and I should probably have narrowed the circulation and utility of my own work. The errors would have been grave, coming from a professed writer on physics, while they were comparatively venial, appearing as they did; for the attentive study of physics had not yet been insisted upon in our systems of professional education. Had Mr. Bell spoken to me on the subject while writing his essay, my future notice of it would probably have been unnecessary; and the opportunity for so speaking was given, as a copy of my work, which he had done me the honour to accept, lay upon his table, and at some of my visits, had been the subject of conversation to us.

Mr. Bell could not desire to mislead the public, and therefore could not regret that any published error of his should be corrected. Some friend of his, however, has taken offence at the above criticism, as appears by the eighth number of the "*Medical Gazette*;" and has hoped to serve Mr. Bell, not by disproving the alleged errors, for he does not even touch upon them, but by charging the author of the "Elements of Physics," with " ignorance,"—" utter incapacity,"—" being a dangerous guide," &c. on the strength of what he supposes three faults, discovered by him in other parts of that work. As his skill in physics, however, seems not to have enabled him to perceive error where it was, the fact of his supposing error where it was not, need not surprise. Accordingly the three portions of the work deemed erroneous by him, *viz.* the illustration of the strength of the scapula, at p. 205, and the proposals of the *Dilator* and *Pneumatic Tractor*, in the last section, are such as I should be pleased to have accounted even favourable samples, and tests of my fitness for the undertaking. I am happy to have to state, that the suspicion that Mr. Bell himself was the author of the attack, is quite unfounded; for he wrote to me on the subject, saying, " the only thing I am anxious about is that you should not suppose I have authorized the counter-statements."

The same defender of Mr. Bell explains the strong resemblance between Mr. B.'s work and mine (which led to the charge of plagiarism in the *Lancet*), by saying that I had taken the whole from previous works of Mr. B. This is nearly as if a friend of any English lexicographer should charge all who write English with copying from his friend's Dictionary; and even if they had used some other. It was not from Mr. Bell's book of Anatomy that I had studied the structure of the human body; and in the present instance I read from the skeleton alone. There is no remark in the few pages of my work which have so unexpectedly to me become thus matter of discussion, which should not occur to almost any person versed in physics, while contemplating the human skeleton. The originality of my essay was in the selection, condensation, and arrangement, under the title (which I believe was new) of *Animal Mechanics*, of some of the most obvious anatomical facts, and in referring these to the physical laws which it was the object of my volume to unfold. That Mr. Bell soon after should have come so near me in these respects, I consider a commendation of my work, and his claiming originality for his own, and not mentioning in his list of previous writings on the subject, mine, which contained the substance of his, except the errors, may have been owing to the hurry with which his was printed, or to his thinking the matter, as in truth it is, of trifling importance.

The same writer further charges it against me, that my reflections on the spine and its diseases, which have been copied from my work into many of the periodicals, are an abstract, unacknowledged, of the late Mr. John Shaw's work on the subject. I should be pleased to think that in my four paragraphs on spinal diseases, I had so happily accomplished, as this censure would imply, the object aimed at throughout my volume, of condensing useful matter; but the fact is, that the paragraphs in question are very nearly the substance of my remarks habitually given to patients under spine disease, before Mr. Shaw's work appeared. My respect for Mr. Bell had led me, from hearing it reported by others, that he descanted ingeniously on the anatomy of the skull, to find room, where few names appeared, for a special commendation of his labours; and had I felt myself called upon, I should not have been behind in regard to Mr. Shaw, for whom, in common with all who knew him, I felt much regard. Mr. Shaw had lent me the skeleton from which in the course of Lectures, of which the present volume records a part, I gave my demonstrations; and which lectures he, with some of Mr. Bell's and his pupils, did me the honour to attend.

At page 237, *after* "*on,*" *line* 2*d.*

on the same extent of

At page 249, *line* 6*th from bottom.*

There are some lakes on the face of the earth which have no outlet towards the sea,—all the water which falls into them, being again carried off by evaporation alone—and such lakes are never of fresh water, because every substance, which, from the beginning of time, rain could dissolve in the regions around them, has necessarily been carried towards them by their feeding streams, and there has remained. The great majority of lakes, however, being basins constantly running over at one part towards the sea, although all originally salt, have in the course of time become fresh, because their only supply, being directly from the clouds, or from rivers and springs fed by the clouds, is fresh, while what runs away from them must always be carrying with it a proportion of any substance that remains dissolved in them. We thus see how the face of the earth has been gradually washed to a state of purity and freshness fitting it for the uses of man, and why the great ocean necessarily contains in solution all the substances that originally existed near the surface of the earth, which water could dissolve:—*viz.* all the saline substances. The city of Mexico stands in the centre of one of the most magnificent plains on the face of the earth, 7,000 feet above the level of the sea, and surrounded by sublime ridges of mountains, many of them snow-capped. One side of the plain is a little lower than the other, and forms the bed of a lake, which is salt for the reasons stated above;—but the lake will not long be salt, for it now has an outlet. About 150 years ago an extraordinary increase of the lake took place, and covered the pavements of the city; an artificial drain was then cut from the plain of Mexico, about sixty miles from the city, to the lower country external to the plain. This soon freed the city from the water; but becoming every year deeper by the wearing effects of the since uninterrupted stream, it is still lowering the surface of the lake, is daily rendering the water less salt, and is converting the vast salt marshes which formerly surrounded the city, into fresh and fertile fields.

At page 258, *after* "*spring*," *line* 9*th.*

If a spring be as low as the bottom of the porous earth from which it issues, that is to say, as low as the surface of the impermeable clay or rock on which the earth rests, it may drain the whole; but if not, the water will stand at a certain level among the earth as it would among bullets in a pit.

At page 277, *after line* 7*th from bottom.*

There is a mode of catching wild ducks, practised in China, which requires that the catcher be well loaded or ballasted. Light grain being first strewed upon the surface of the water to tempt them, a man hides himself in the midst of it, under what appears a gourd or basket drifting with the stream, and when the flock approaches and surrounds him, he quickly obtains a rich booty by snatching the creatures down one by one—making them appear as if they were diving, and then securing them below. Each bird becomes as a piece of cork attached to his body.

At page 278, *for last* 5 *lines substitute.*

A floating body, to be stable in its position, must either have its centre of gravity below the centre of gravity of the fluid which it displaces—called the *centre of buoyancy*, or it must have a broad bearing on the water, so that any inclination may cause its centre of gravity to ascend.

At page 284, *after* "*season*," *line* 19*th.*

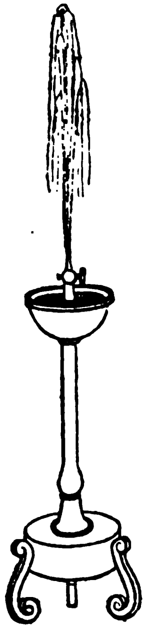
Not only is the extreme of cold below thus prevented, but because water becomes more bulky in proportion as its temperature falls under forty degrees, very cold water remains floating on the surface of a wintry lake, as cream floats on milk, and preserves underneath that warmth which is agreeable to the fishes, just as very hot water in summer remains uppermost, preserving underneath an agreeable coolness.

At page 286, *after* "*nature*," *line* 2*d from bottom.*

The atmosphere is about fifty miles high or deep, and therefore, in relation to the bulk of the earth, is as a covering of one-tenth of an inch in thickness to a common library globe of a foot in diameter.

At page 296, *after line* 2*d.*

A table-lamp thus, by the pressure of condensed air, may be supplied with oil from a reservoir far below the wick: and lately an enema-syringe, and a shower-bath have been constructed on the same principle.



At page* 303, *after line 5th.

This fountain may have its parts concealed under a variety of graceful forms, as that here represented; and then it becomes a beautiful ornament among flowers in a summer drawing-room.

It may be made to play for an hour or more, and will always recommence on the water being shifted from the low to the high reservoir.

***At page* 320, *after "relation," line* 15*th* (**p.* 331).**

This truth is well exemplified in what may be called the *syphon-paradox*, an exact counterpart of the paradox of the "Hydrostatic Bellows," already explained. The syphon-paradox may be exhibited by reversing the apparatus of the bellows. If this apparatus be filled with water in the ordinary way (see page 232), and be then turned so that the tube becomes like the long leg of a syphon, the little stream of water issuing from it at *a* will lift as great a weight suspended *from* the board *d*, as the same slender column in the standing position can lift *upon* the board. Farther illustrative of the atmospherical pressure exerted in producing this effect and in rendering a syphon active, we may advert to the striking fact, that a long small tube of water screwed into the side or bottom of a close cask of water so as to communicate with it, and then allowed to discharge like the long leg of a syphon, will cause the cask to be burst inwards, just as the same tube screwed into the top of the cask, as represented at page 231, would cause the cask to be burst outwards.

At page 332, *after line* 18*th* (* *p.* 343).

A barometer is of great use to persons employed about those mines in which *hydrogen gas*, or *fire-damp*, is generated and exists in the crevices. When the atmosphere becomes unusually light, the hydrogen being relieved from a part of the pressure which ordinarily confines it to its holes and lurking-places, expands or issues forth to where it often meets the lamp of the miner, and explodes to his destruction. In heavy states of the atmosphere, on the contrary, it is pressed back to its hiding places, and the miner advances with safety.

At page 336, *after "recover," line* 10*th.*

In the elevated plains of South America, the inhabitants have larger chests than the inhabitants of lower regions—exhibiting another admirable instance of the animal frame adapting itself to the circumstances in which it is placed.

At page 349, *after "that," line* 10*th.*

high-pressure steam is merely *condensed steam*, as *high-pressure air* is *condensed air*, in other words,

At page 357, *after "alone," line* 7*th* (* *p.* 369.)

—the same steam thus doing double work or more. All the advantages of the two cylinders, however, are obtainable from the single cylinder as now used in most of the Cornish mines. Steam of about 40lbs. pressure on the inch is admitted to the cylinder, until the piston is driven one-third of its way, and the valve being then shut, the same steam is left to finish the stroke by its expansion alone. The pressure of the expanding steam gradually diminishes, it is true, in proportion as the volume increases; but in pumping water there is a great saving of time, from having the power more intense at the beginning of the stroke, when the vast mass of water and machinery has first to be put into motion.

At page 372, *after line 5th.*

but Mr. Daniel (see his excellent work, entitled Meteorological Essays) has lately given to the philosophical world a correct and simple instrument for the purpose. It depends on the principle explained above, that whenever a body in the atmosphere has a temperature below that at which the quantity of watery vapour in the air around can be maintained in the aeriform or invisible state, dew forms on the body. By cooling a bulb of glass until moisture begins visibly to settle upon it, and then noting the temperature on an enclosed thermometer, the proportion of water mixed with the air is discovered.

At page 378, *after "abandoned," line 20th.*

A balloon has since been thought of as a means by which travellers might obtain information, while penetrating into unknown countries, like the almost interminable plains of *Australasia.*

At page 382, *after line 13th.*

A piece of burning paper thrown upon the top of a half-extinguished fire, often makes it blaze afresh, by causing a more rapid current of air to pass throught it from below.

At page 394, *after line 23d.*

The reason why the trade-winds at their external confines, which are about 30° from the sun's place, appear almost direct *east* and become more nearly *north* and *south* as they approach the central line, is, that at the confine they are like fluid coming from the axis of a turning wheel, which has approached the circumference, but has not yet acquired the velocity of the circumference; while, nearer the line, they are like the fluid after it has for a considerable time been turning on the circumference, and has acquired its rotary motion, appearing at rest as regards that motion, but still leaving sensible any motion in a cross direction.

While, in the lower regions of the atmosphere, air is constantly flowing towards the equator and forming the steady trade-winds between the tropics, in the upper regions there must of course be a counter-current distributing the heated air again over the globe. Accordingly, since reasoning led men to expect this, many striking proofs have been noted. At the summit of the Peak of Teneriffe, observations now prove that there is always a strong wind blowing in a direction contrary to that of the trade-wind on the face of the ocean below. Again, the trade-winds among the West-India Islands are constant, yet volcanic dust thrown aloft from the Island of St. Vincent, in the year 1812, was found, to the astonishment of the inhabitants of Barbadoes, hovering over them in thick clouds, and falling, after coming more than 100 miles directly against the strong trade-wind, which ships must take a circuitous course to avoid. Persons sailing from the Cape of Good Hope to St. Helena, often find the sun hidden for days together by a stratum of dense clouds passing southward high in the atmosphere; which clouds consist of the moisture raised near the equator with the heated air, and becoming condensed again as it approaches the colder regions of the south.

At page 395, *after "wind," line 7th.*

In many situations beyond the tropics the westerly winds, which are merely the upper equatorial currents of air falling down, are almost as regular as the easterly winds within the tropics, and might also be called trade-winds:—witness the usual shortness of the voyages from New York to Liverpool, and the length of those made in the contrary direction.

At page 403, *after* "*it*," *line* 12*th from bottom.*

and when only twice as much water is forced out, there is still four times as much work done, because each particle issues with twice the force or velocity.

At page 406, *after line* 13*th.*

It is said that boats having to reach the shore through a raging surf, have been preserved by the crews first spilling a cask of oil in the offing.

At page 415, *after line* 3*d from bottom* (* *p.* 432).

Thus, even if the resistance at the bow of a vessel were all that had to be considered, the force of one hundred horses would only drag the vessel ten times as fast as the force of one horse. But there is another important element in the calculation, *viz.* the lessening of the usual water-pressure on the stern of the vessel as she moves forward, on account of which, the force required to produce an increased velocity is still considerably greater than as noted in the table.

At page 421, *after line* 8*th from bottom.*

The explanation is, that a flat or plane surface throws the particles of fluid almost directly outwards from its centre to its circumference—the convex or wedge-like surface again, while displacing them just as far, still does it more slowly, and therefore with less expenditure of force, in proportion as its point is in advance of its shoulder or broadest part—and a concave surface must give to some of the particles a forward as well as a lateral motion. The shape of the hinder part of a solid moving through a fluid is of importance for corresponding reasons.

At page 429, *after line* 5*th from bottom.*

The reason why a ship generally sails faster with the wind from one side, than when it is from directly astern, is, that in the former case all the sails are acting, although individually not to the best advantage, while in the latter, the sails in front are becalmed by those behind them. A ship with a side-wind may move faster than the wind, as is often true of the outer extremities of a windmill's vanes.

At page 435, *after line* 8*th from bottom..*

An exhibition has lately been made (October 1827) of a car drawn along the highways by kites. That they might ascend to a great elevation, where the wind is generally stronger than below, they were attached to each other in a row, so that the second kite mounted as if its cord were held by a hand at the first, the third as if rising from the second, and so forth. The projector of this novelty hoped that he had pointed out a most valuable means of travelling across extensive plains, sandy deserts, tracts of snow, &c., and, in all cases, nearly with the speed of the wind.

At page 468, *after line* 9*th from bottom.*

A superstitious man sleeping in the upper story of a lofty house, had long heard, during the stillness of night, a singular beating noise near the head of his bed. There was nothing going on near him, or indeed in the whole house, to account for it, and he at last deemed it supernatural. Accident, however, discovered that in a cellar at the bottom and outside of the wall against which his bed stood, there was a wooden clock hanging, of which the sound became audible aloft.

At page 477, *after line* 15*th.*

The wide-spread sail of a ship, rendered concave by a gentle breeze, is also a good collector of sound. It happened once on board a ship sailing along the coast of Brazil, 100 miles from land, that the persons walking on deck, when passing a particular spot, always heard very distinctly the sound of bells, varying as in human rejoicings. All on board came to listen, and were convinced, but the phenomenon was mysterious and inexplicable. Months afterwards it was ascertained, that at the time of observation the bells of the city of St. Salvador, on the Brazilian coast, had been ringing on the occasion of a festival—their sound, therefore, favoured by a gentle wind, had travelled over 100 miles of smooth water, and had been brought to a focus by the sail in the particular situation on the deck where it was listened to.

At page 550, *after* "*required*," *line* 1*st.*

It is most important to remark here, that if air be injected into the lungs, either in too large quantity or very suddenly, instead of recalling or sustaining life, it is as certain a means of killing as a dagger driven through the heart. This truth has been but lately known, and ignorance of it has probably decided the fate of many persons, treated with a view to recovery after submersion. The operator should reflect that he is dilating the delicate air-cells of the lungs with the force of an hydraulic press; and that if he do so very suddenly, although little, he still may rupture many small blood-vessels, before they can empty themselves so as to yield. In a bellows for the purpose of artificial respiration, there should be the means of checking its opening to suit the capacity of the patient's chest, and there should be a cock in the pipe or nozzle, to regulate the speed of the passing air.

At page 565, *after line* 10*th from bottom* (* *p.* 589).

Should stuttering ever arise from the attempt being made to speak while drawing air into the chest (which I much doubt), it may then be avoided by filling the chest well before beginning to speak.

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